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Groundwater Quality Monitoring Recommendations for Western Surface Coal Mines

Kaman Tempo, Santa Barbara, CA

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GROUNDWATER QUALITY MONITORING RECOMMENDATIONS FOR WESTERN SURFACE COAL MINES

by

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SECTION 1

INTRODUCTION

In recent years the nation has become increasingly dependent on imported foreign oil to meet its energy requirements. With rapidly escalating costs and decreasing security of domestic petroleum resources, many Government officials have advocated a shift from the use of foreign oil to the use of domestic coal. Coal in the Western United States may represent an important part of the solution to the nation's energy problems. In many areas, these coal beds are relatively shallow, thick, and flat-lying and, therefore, may be readily mined by rapid and economical surface mining methods. Although coals of the Western United States are distant from the established energy-consumptive industrial areas of the East and have a lower energy content than eastern coals, the lower mining costs and reduced sulfur content of western coals tend to make them an acceptable and, in many cases, advantageous energy source. The low sulfur content of western coal tends to minimize air quality impacts at locations where it is consumed. As in the development of most earth resources, however, mining operations have the potential for contaminating water supplies by disturbing the local environmental equilibrium.

In the Western United States water is generally scarce and usually represents a limiting factor in local and regional development. Therefore, while obtaining needed coal supplies, these valuable water resources must be conserved and protected from damage. Accordingly, this report is oriented toward conservation and protection of groundwater by development and presentation of a groundwater monitoring methodology. The objective of this study is to develop an exhaustive set of source-specific groundwater quality monitoring recommendations to guide government and industry representatives concerned with western coal strip mine programs.

This report is a compendium of potential groundwater monitoring activities. The identified list of monitoring activities is not envisioned as universally applicable to western surface coal mine sites. It should serve as a reference to assist in the development of groundwater monitoring programs for specific site conditions, characteristics of the mining operation, and types of potential groundwater quality contamination.

The report is structured to permit selecting from the table of contents specific potential pollution sources that may be present at a given mine site. Monitoring recommendations for each source are independently developed in the report to allow the user to quickly obtain those recommendations that are relevant to his mine site. Because this listing of sources is presented in a handbook style, it does not lend itself to continuous reading. Each source description is independent by design and, consequently, the methodology is repeated for each source. No overall summary or conclusion section is included since the report is composed of sections that are complete within themselves.

GROUNDWATER MONITORING METHODOLOGY

The U.S. Environmental Protection Agency (EPA) is responsibile under the Federal Water Pollution Control Act Amendment of 1972 (Public Law 92-500) and the Safe Drinking Water Act of 1974 (Public Law 92-523) to prevent, reduce, and eliminate groundwater quality degradation. In view of this responsibility, the EPA developed a methodology to monitor the effects of human activities on groundwater quality (Todd et al., 1976). The methodology was applied to two types of energy-related activities in the Western United States--oil shale extraction and surface coal mining.

The monitoring recommendations presented in this report follow a systematized 8-step methodology that has evolved from an earlier 15-step version (Todd et al., 1976). The methodology is partially based on characterization of the hydrologic system involved and is described later under the heading "Groundwater Pollution System." The eight steps used here are shown in Table 1-1.

TABLE 1-1. GROUNDWATER MONITORING METHODOLOGY

Step 1.	Select study area for monitoring
Step 2.	Inventory potential pollution sources and methods of disposal
Step 3.	Identify potential pollutants
Step 4.	Identify groundwater usage
Step 5.	Evaluate infiltration potential
Step 6.	Evaluate pollutant mobility in vadose zone
Step 7.	Evaluate pollutant mobility in saturated zone
Step 8.	Prioritize sources
	a. Potential pollutant amounts and concentration
	b. Amounts infiltrating
	c. Mobility of infiltrating pollutants in vadose zone
	d. Mobility of pollutants reaching saturated zone

Step 1 is directed toward the selection of study areas for groundwater monitoring based on certain administrative and physiographic considerations. These considerations are used to divide a State (or area under consideration) into manageable study units. Once these are established, study area priorities should be evaluated using available information on the types and numbers of potential pollution sources present in each area. In some instances, sufficient information may be available in order to arrive at priorities. In many instances, only limited information will be available, and Step 2 of the methodology will assist in obtaining the necessary information. In instances where the monitoring methodology is to be applied to a particular mining operation, the study area is initially known and site and operations information may be sufficient to prioritize study areas.

Step 2 of the methodology includes a detailed inventory of potential sources of pollution and methods of waste disposal in the study area. During Step 2, a comprehensive priority listing of potential groundwater pollution sources should be attempted. Results of this initial evaluation will be enhanced by knowledge of case histories of groundwater contamination that have resulted from similar sources in similar environments.

Since this report is intended to present monitoring recommendations for a series of generic groundwater pollution sources related to coal strip mining, no reference is made to any specific mine site. Step 8 is the priority ranking scheme presented in Everett (1979) and requires mine-specific data for each of the Steps 1 through 7. Potential sources of pollution are ranked in terms of the four substeps of Step 8. Steps 3, 5, 6, and 7, however, are fully discussed for each of the pollution sources.

A coal mine operator planning to use the monitoring methodology would select those potential sources associated with his operation from the list given in Table 1-2. Funds allocated to each potential source for development of an appropriate monitoring program would be based on relative significance. To develop this program, Steps 3 through 8 of the methodology would be applied to each source in order of the source's priority or importance at the particular mine site. The priority of the pollutant source can be established by identifying the individual potential pollutants involved (Step 3), the intended uses of the water (Step 4), the infiltration rate of the pollutants (Step 5), the rate of movement of the pollutants in the vadose zone (Step 6), and the rate of pollutant movement in the saturated zone (Step 7). The primary goal is to evaluate the effectiveness of monitoring for each of the existing sources and determine the potential for groundwater contamination from each source based on the priority established in Step 8.

SURFACE COAL MINING TECHNOLOGIES

General Characteristics of Surface Mining

Important advantages usually cited for the surface mining of coal are relatively high rates of production and low cost. Generally, the greatest effort and largest cost factor in surface mining is stripping and replacing overburden. Thus, for a given thickness and quality of coal, optimal mining conditions exist where geologic conditions facilitate stripping (e.g., where the coal deposits are large and flat-lying with thin, uniform overburden that is easily fragmented). Irregular topography causes undesirable and sometimes locally restrictive variations in thickness of overburden. With dipping beds, the thickness of overburden increases in a down-dip direction to a point where

TABLE 1-2. RANKING OF POTENTIAL SOURCES OF GROUNDWATER POLLUTION FROM SURFACE COAL MINING OPERATIONS (after Everett, 1979)

1. Spoils
2. Pit water
3. Sedimentation ponds
4. Explosives
5. Mine solid waste and shop liquid wastes
6. Sanitary waste
7. Spills
8. Leaks
9. Stockpiles
   a. Topsoil
   b. Overburden
   c. Coal
   d. Coal refuse
   e. Partings
10. Reclamation aids
11. Solid waste from road construction

continued mining is uneconomical. Under present equipment limitations, it is difficult to mine at depths much greater than 200 feet.*

The type of geological material in the overburden, whether it is solid bedrock that is difficult to break up and load or soft or fractured rock, is an important cost factor. The quality of the overburden and the degree to which selective handling is necessary must also be considered. The ratio of overburden thickness to recoverable coal thickness may provide a rough rule of thumb for mining feasibility. A low ratio, in many instances, is advantageous in terms of recovery, grade control, flexibility of operation, safety, and general working environment. Various other economic factors, including availability of markets, market value, distance of transport, and, more recently, the cost of environmental protection, are included as factors in such a rule of thumb, as well as in other more detailed economic evaluations of the coal and its development potential.

---

* See Appendix A for conversion to metric units. English units are generally used in this report because of their current usage and familiarity in industry and the hydrology-related sciences. Certain units, expressed in commonly used metric units (e.g., concentrations), are expressed as milligrams per liter or similar units.

Commonly used surface mining and reclamation procedures and sequences of operation vary among different areas and mines because of physical and economic conditions, local availability of equipment, and other conditions. The following brief outline is broadly representative of western surface coal mining procedures, including those that may affect groundwater.

Planning and Exploration

In planning for mining and reclamation of a coal property, a number of geographic and geologic factors must be considered. Climatic conditions, including rainfall, temperature, and other weather conditions, may affect the physical characteristics of the earth materials that must be handled, the types of equipment required, annual working days, general efficiency of the operation, and reclamation practices. Geologic and surface topography influence the design of the pit as well as equipment type and mining and reclamation procedures. Topographic and geologic mapping and exploratory drilling are usually needed to obtain information on the thickness, character, dip, and strike of the overburden and coal and on subsurface water conditions. Systematic coring of the overburden and coal throughout a proposed mine yields samples for detailed physical and chemical analyses.

Mining and Reclamation

An initial step in uncovering the coal seam that is to be mined is removal of topsoil and subsoil from the area and stockpiling for replacement over spoils or other disturbed areas during reclamation. Scrapers are used for removing soil.

Overburden that lies between the soil and the coal seam is removed or stripped to expose the coal, using combinations of shovels, draglines, scrapers, and bulldozers. Typically, stripping and subsequent removal of the exposed coal occur in alternating sequence along a series of elongated, parallel "cuts" designed to uncover the area of proposed mining. The overburden is progressively removed along one cut at a time. The waste overburden (or spoil) is dumped into the adjacent parallel cut from which coal had been previously removed. Toxic or acid-forming materials with a high potential for causing environmental contamination are selectively removed, stored, and ultimately placed in the spoils or on the surface in a location and manner to minimize future leaching or mobility of the potential contaminants.

The exposed coal is drilled and fractured with explosives, as necessary, thereby facilitating loading of coal by mechanical shovels. From the pit, the coal is hauled by truck or conveyor belt to the preparation plant where, commonly, it is crushed, screened, sized, and graded, and then loaded on railroad cars or trucks for transport to a more distant point for further processing and/or usage. Western coals are very seldom washed. Upon completion of coal removal, overburden is graded, surface drainage patterns restored, and topsoil and subsoil respread and seeded.

RELATION OF SURFACE MINING TO POTENTIAL GROUNDWATER POLLUTION

Mine-Related Sources of Potential Contaminants

Surface mining operations may result in basic environmental changes which, in turn, can cause or contribute to groundwater pollution. These changes can be classified as: (1) disturbances of the solid earth materials, (2) disturbances of the surface water and groundwater, and (3) introduction of miscellaneous foreign liquid and solid materials into the local environment. Discussions of specific "sources" of potential pollutants (as shown in Figure 1-1) resulting from mining follow.

Excavation of solid materials, which may have been protected from chemical and physical interaction with circulating water and air, and the storage or deposition of these materials on the surface may lead to release of pollutants to the hydrologic environment. Depending on the particular mining operation, these stored or deposited materials may consist of constituents of the coal and overlying zones, such as soils, overburden from between the soil and coal zones, rider coal seams or coal stringers, coal waste, coal refuse, and partings.

Most of the overburden that overlies the coal seam and must be removed to expose the coal for mining is immediately placed in an adjacent or nearby part of the pit from which coal has been removed. As soon as practicable, the rough surface of these "spoils" is reclaimed (i.e., recontoured, soils replaced, and seeded). This tends to minimize the release of potential contaminants from the spoils by reducing infiltration and exposure to water, air, and wind erosion. In many instances, earth materials and wastes from the general mining operations that are potentially toxic, acid forming, or otherwise environmentally threatening are selectively placed at protected locations within the spoils zone.

Although permanently buried spoils are better protected from the elements than those displaced materials that are temporarily or permanently placed on the surface, they are major potential contributors to groundwater contamination because of their large volume and geohydrologic characteristics. Also, because of their subsurface location, spoils above or below the water table may more readily transmit contaminants directly to the groundwater zone. In comparison, only limited contaminants released from surface sources may reach the groundwater zone, due to possible diversions to other surface locations and greater attenuation along the generally more lengthy and circuitous route to the groundwater zone. Air entrapped during backfilling of the spoils or moving into the spoils through available openings may appreciably increase the potential for oxidation and dissolution of certain mineral constituents in the spoil material.

In addition to the disturbed solid earth materials, several other mine-related sources of potential groundwater contaminants exist. The most important of these are pit water and sedimentation pond water. Pit water is composed of surface water and groundwater that collects in open pits from which the coal and overburden have been removed. Water in sedimentation ponds is collected from surface runoff and pit sources. Both pits and sedimentation

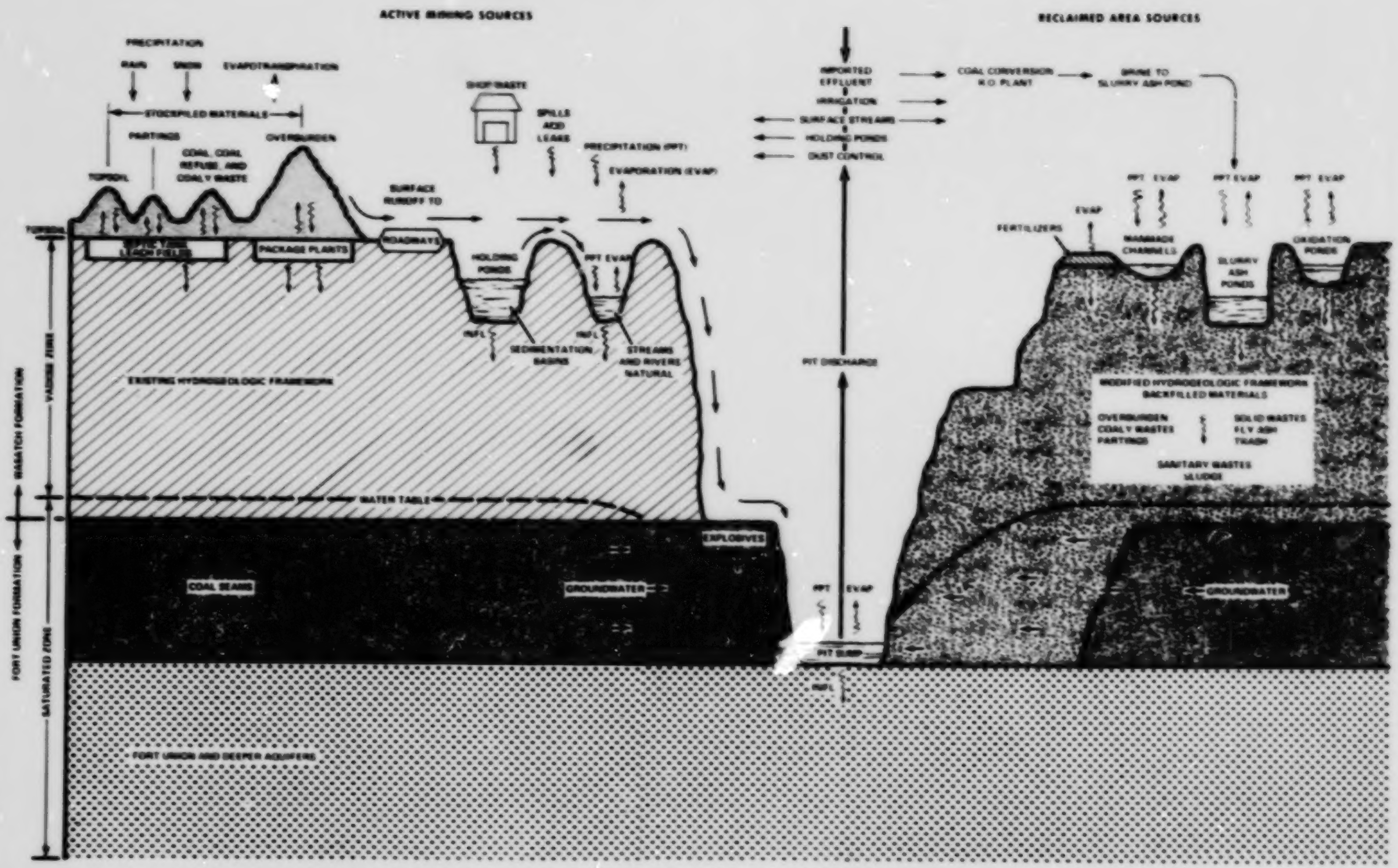
ACTIVE MINING SOURCES
RECLAIMED AREA SOURCES
PRECIPITATION
RAIN
SNOW
EVAPOTRANSPIRATION
STOCKPILED MATERIALS
PARTINGS
COAL, COAL REFUSE, AND COALY WASTE
OVERBURDEN
TOPSOIL
SEPTIC TANK LEACH FIELDS
PACKAGE PLANTS
SURFACE RUNOFF TO
ROADWAYS
SHOP WASTE
SPILLS AND LEAKS
PRECIPITATION (PPT)
EVAPORATION (EVAP)
HOLDING PONDS
PPT EVAP
INFL
SEDIMENTATION BASINS
STREAMS AND RIVERS NATURAL
EXISTING HYDROGEOLOGIC FRAMEWORK
WATER TABLE
EXPLOSIVES
COAL SEAMS
GROUNDWATER
FORT UNION AND DEEPER AQUIFERS
WASATCH FORMATION
FORT UNION FORMATION
VADOSE ZONE
SATURATED ZONE
IMPORTED EFFLUENT
IRRIGATION
SURFACE STREAMS
HOLDING PONDS
DUST CONTROL
PIT DISCHARGE
PIT SUMP
COAL CONVERSION R.O. PLANT
BRINE TO SLURRY ASH POND
FERTILIZERS
EVAP
DRAINAGE CHANNELS
SLURRY ASH PONDS
OXIDATION PONDS
MODIFIED HYDROGEOLOGIC FRAMEWORK BACKFILLED MATERIALS
OVERBURDEN
COALY WASTES
PARTINGS
SOLID WASTES
FLY ASH
TRASH
SANITARY WASTES
SLUDGE

Figure 1-1. Potential pollution source interrelationships--western surface coal mining operations.

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ponds may collect water that is already naturally or artificially contaminated, or the water may become contaminated by contact with coal or rock materials in the pit or pond. Concentrations of dissolved solids also may increase due to evaporation. Subsequently, seeps or other discharges from the pit or pond may enter and contaminate groundwater zones. Under most conditions, the chemical quality of waters in pits and ponds is not sufficiently poor so as to damage the hydrologic balance. However, miscellaneous byproducts or wastes from mine operations may be released to the environment and become potential groundwater contaminants. These wastes include explosives, shop wastes, sanitary wastes, spills, leaks, and reclamation aids.

Relative Contamination Potential of Sources

The schematic cross section of a surface coal mine in Figure 1-1 shows the interrelations of various contaminant "sources," the disturbed environment, and the undisturbed environment. As indicated in Table 1-2, spoils are ranked as having the highest groundwater pollution potential at typical mining operations because, at most locations, they comprise a large volume of disturbed earth material that is subject to leaching by water in the vadose and saturated zones (Everett, 1979). The priority ranking for specific mines should be based on a sequence of data compilation and the evaluation steps of Table 1-1. The three basic criteria used to develop a site-specific source pollutant ranking include:

- Potential mobility
- Waste characteristics, i.e., volume, persistence, toxicity, and concentration
- Usability.

Guidelines for monitoring these sources of potential groundwater pollution are presented in Section 3, Monitoring Recommendations for Active Mine Sources of Pollution, and Section 4, Monitoring Recommendations for Reclaimed Mine Sources of Pollution.

Groundwater Pollution Model

Effective counteraction against potential or existing groundwater pollution requires an understanding of the sequences of processes and conditions involved in the transport of pollutants from a source to the groundwater zone. Through analysis of the potential pollutants, the local environmental conditions, and their possible interactions at a mine site, it is possible to develop a diagrammatic model of part of the total hydrologic cycle of groundwater pollution. Since the hydraulics of water movement from the land surface to the saturated zone are of secondary interest, this model emphasizes the physical, chemical, and biological processes that contribute to or limit the potential for groundwater pollution. It assists in visualizing the movement and effects of pollutants in the hydrologic cycle as they relate to the various steps in the methodology.

Figure 1-2 illustrates the sequence of hydrologic processes and conditions considered by the model. With the model, it may be possible to identify critical stages in the contamination process where countermeasures that prevent, minimize, or mitigate pollution are necessary. The component processes and conditions will vary in detail from one mine site to another. Total knowledge of the groundwater system is not likely to be available at any location. However, the available information, augmented by reasonable hypotheses, is often sufficient to provide a workable model, or possibly several alternative ones, that can be used as a starting point in countering pollution. Even where data are grossly inadequate, it is worthwhile to construct one or several best-possible alternative conceptual models of the probable and possible local groundwater contamination systems for use in planning an initial data collection program. In all situations, the accuracy of the model and its usefulness in designing pollution countermeasures are upgraded as additional data are gathered and evaluated.

The groundwater pollution system has a number of basic component processes and conditions, each with a particular function in the overall system (Figure 1-2). After examination of the components of the system and their functions, it becomes apparent that pollutant transport is analogous to a conventional transportation system. Steps 3 through 7 in the monitoring methodology, which relate to the pollutants and their interaction with the earth environment, correlate with components of the pollution system, as indicated in Figure 1-2. Thus, by following the steps of the methodology, an understanding of the pollutant-environment interrelations and of other factors needed in monitoring design is achieved.

GROUNDWATER POLLUTION PATHWAYS

Transportation/Mobility

As further illustrated in Figure 1-2, the pollution system diagram (which also shows the steps for the groundwater monitoring methodology) shows the source of pollutants to be on the land surface. With the exception of the "infiltration" component, however, the diagram is equally applicable to underground sources. In a typical case of groundwater pollution, there is a "source" (origin) of the polluting material, a "vehicle" for transport of the pollutant, and one or more "routes" along which the pollutant is transported to a groundwater "destination." Typically, the transporting agent is water in which the pollutant is suspended or dissolved. Wind is an important transporting agent in some instances. In less common instances, animals, vegetation, or even gravity (e.g., earth slides) may act as transporting agents. In the case of water transport, gravity is usually the force moving pollutants from a higher to a lower elevation. Under some relatively unusual conditions, subsurface pollutants might be transported by artesian groundwater flow from a lower to a higher location. Under unsaturated conditions, water solutions can be moved either upward or downward by capillary forces.

APPLICATION TO WESTERN SURFACE COAL MINING

As a means to illustrate how the groundwater monitoring methodology may be applied to western surface coal mining operations, Campbell County, Wyoming

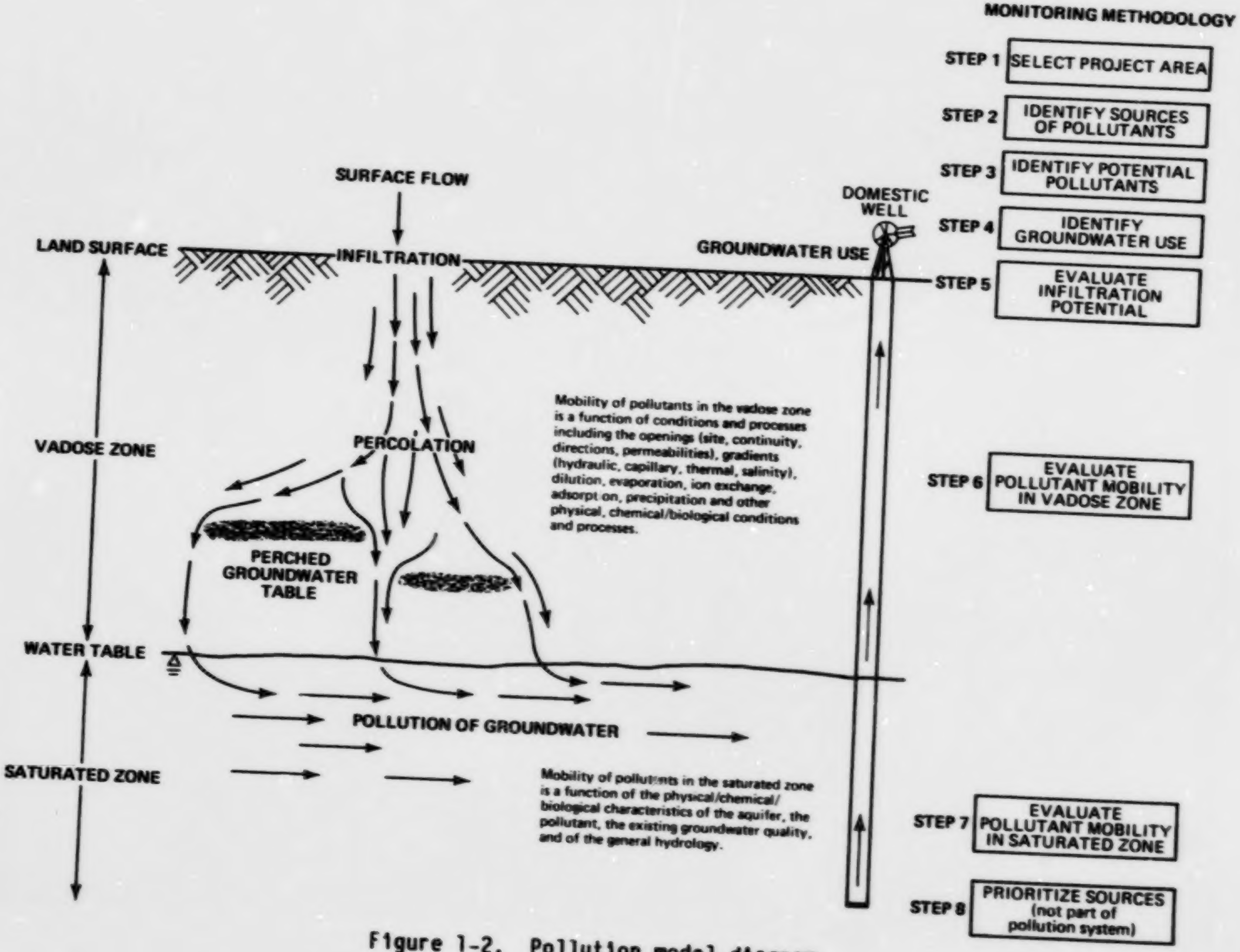
MONITORING METHODOLOGY
STEP 1 SELECT PROJECT AREA
STEP 2 IDENTIFY SOURCES OF POLLUTANTS
STEP 3 IDENTIFY POTENTIAL POLLUTANTS
STEP 4 IDENTIFY GROUNDWATER USE
STEP 5 EVALUATE INFILTRATION POTENTIAL
STEP 6 EVALUATE POLLUTANT MOBILITY IN VADOSE ZONE
STEP 7 EVALUATE POLLUTANT MOBILITY IN SATURATED ZONE
STEP 8 PRIORITIZE SOURCES (not part of pollution system)
SURFACE FLOW
DOMESTIC WELL
GROUNDWATER USE
LAND SURFACE
INFILTRATION
VADOSE ZONE
PERCOLATION
Mobility of pollutants in the vadose zone is a function of conditions and processes including the openings (site, continuity, directions, permeabilities), gradients (hydraulic, capillary, thermal, salinity), dilution, evaporation, ion exchange, adsorption, precipitation and other physical, chemical/biological conditions and processes.
PERCHED GROUNDWATER TABLE
WATER TABLE
POLLUTION OF GROUNDWATER
SATURATED ZONE
Mobility of pollutants in the saturated zone is a function of the physical/chemical/biological characteristics of the aquifer, the pollutant, the existing groundwater quality, and of the general hydrology.

Figure 1-2. Pollution model diagram.

has been chosen as an example study area. However, the recommendations outlined in this document are intended to apply to individual mine sites throughout the western states.

Potential sources of groundwater pollution from surface coal mining have been identified through research, interviews, and site visits to mines in the Powder River Basin. Each of these potential pollution sources is presented separately. A source-specific monitoring program is developed for each source by following Steps 3 through 7 of the methodology. Under each step, existing data for the study area are examined, monitoring methods are identified, possible alternative monitoring approaches are discussed, and a monitoring scheme is recommended. Once Steps 3 through 7 are completed, recommended monitoring approaches for each step are integrated into an overall monitoring program (Step 8) for a specific mine. A computer interactive systems version of the EPA groundwater quality monitoring methodology given in Everett and Rasmussen (1982) can be used to assist in this process.

By following the format presented in this guideline, a user will be able to develop a groundwater monitoring program that is tailored to a specific mine. Information included in this report is based on: (1) field studies and monitoring at coal mine sites located throughout the western coal-producing states, (2) background acquired during continuing studies of groundwater pollution and monitoring over a period of 10 years, and (3) the accumulated personal experience of a number of specialists who contributed to this study.

SECTION 2

PROJECT DEFINITION

THE PROJECT MONITORING AREA

Although the example project area used in this report is located in Campbell County, Wyoming (see Figure 2-1), the groundwater monitoring recommendations have been expanded to include all western coal strip mining operations. Campbell County is the largest producing coal field in the Western United States and contains about 50 percent of Wyoming's coal resources and approximately 84 percent of its known strippable coal. At least 20 billion tons lie within 200 feet of the surface and are recoverable by surface mining methods (Breckenridge et al., 1974). Within the project area (Figure 2-2), several coal mines at various levels of production were identified. The majority of the examples used in this report are taken from the seven mines identified in Figure 2-2. The majority of the potential pollution problems associated with coal strip mining were assumed to be represented by the seven mines; therefore, the monitoring recommendations have been generalized to cover all western coal strip mine development.

GENERIC MONITORING STEPS

Before evaluating monitoring needs for individual sources of potential pollution from surface coal mining activities, Steps 1, 2, and 4 of the methodology must be addressed.

Step 1. Select Area or Basin for Monitoring

The selection of areas to be monitored (on an areawide basis) will be made within a State by a designated monitoring agency (DMA). The DMA may be a Federal or State agency charged with developing the monitoring program. The basis for selecting areas will be governed, in general, by a combination of administrative, physiographic, and priority considerations. For a coal mining operation, the operator is required to monitor the hydrologic balance within the "mine plan and adjacent areas" of the mine. These monitoring areas are defined in the OSM Permanent Regulatory Program at 30 CFR 701.5 (and approved State regulatory programs) and include the area to be disturbed by mining and the surrounding lands where surface or groundwaters may be adversely affected by coal mining and reclamation operations. The operator's identification of the mine plan (or permit) and adjacent areas fulfills the requirements of Step 1 of the methodology.

Administrative Considerations--

The initiation of an areawide groundwater monitoring program requires specification of a local DMA. In many situations, the requisite agency with the necessary technical staff will be the designated coal regulatory authority in the State (possibly cooperating with other county, district, or regional organizations). The size of a particular area may vary from a few square miles to thousands of square miles. Size alone is less important than the ready assessibility of all portions of the area to the DMA as well as hydrogeologic knowledge of the area by the DMA.

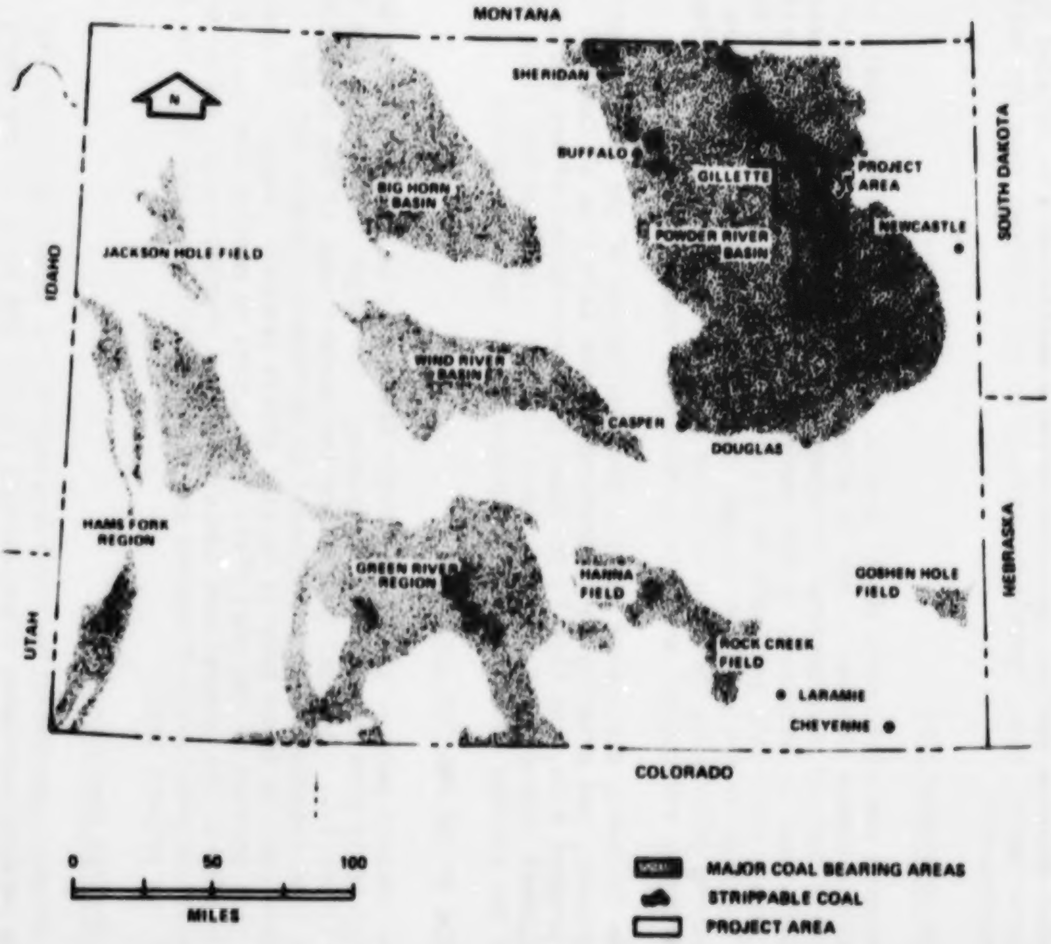
MONTANA
N
SHERIDAN
BUFFALO
GILLETTE
PROJECT AREA
NEWCASTLE
SOUTH DAKOTA
BIG HORN BASIN
POWDER RIVER BASIN
JACKSON HOLE FIELD
IDAHO
WIND RIVER BASIN
CASPER
DOUGLAS
HAMS FORK REGION
GREEN RIVER REGION
HANNA FIELD
GOSHEN HOLE FIELD
NEBRASKA
UTAH
ROCK CREEK FIELD
LARAMIE
CHEYENNE
COLORADO
0
50
100
MILES
MAJOR COAL BEARING AREAS
STRIPPABLE COAL
PROJECT AREA

Figure 2-1. Major coal fields of Wyoming (adapted from U.S. Geological Survey, 1974).

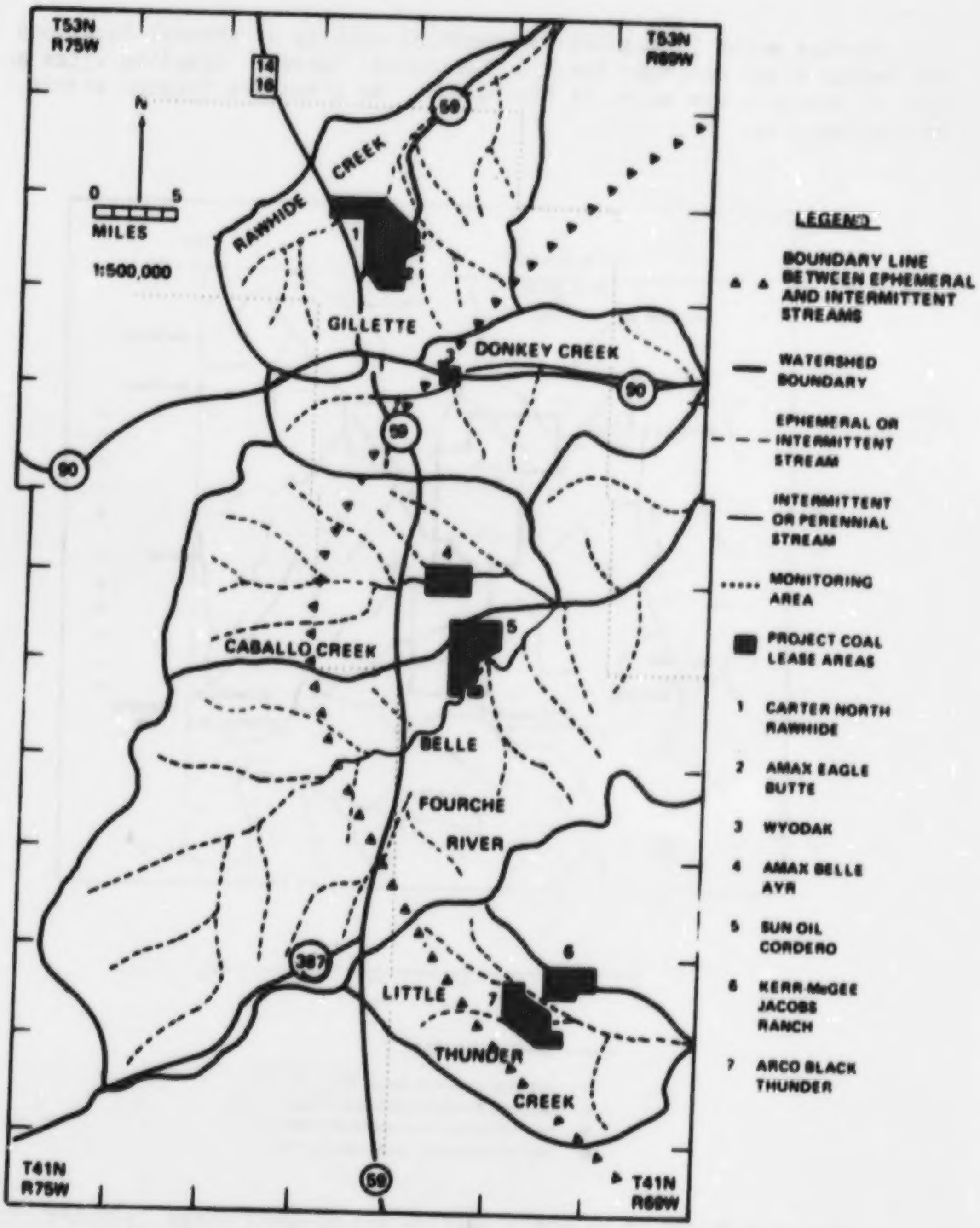
T53N
R75W
T53N
R69W
14
16
59
N
0
5
MILES
1:500,000
RAWHIDE CREEK
1
GILLETTE
DONKEY CREEK
2
3
90
59
90
4
5
CABALLO CREEK
BELLE
FOURCHE
RIVER
387
6
LITTLE
7
THUNDER
CREEK
T41N
R75W
59
T41N
R69W
LEGEND
BOUNDARY LINE BETWEEN EPHEMERAL AND INTERMITTENT STREAMS
WATERSHED BOUNDARY
EPHEMERAL OR INTERMITTENT STREAM
INTERMITTENT OR PERENNIAL STREAM
MONITORING AREA
PROJECT COAL LEASE AREAS
1 CARTER NORTH RAWHIDE
2 AMAX EAGLE BUTTE
3 WYODAK
4 AMAX BELLE AYR
5 SUN OIL CORDERO
6 KERR McGEE JACOBS RANCH
7 ARCO BLACK THUNDER

Figure 2-2. Map of project monitoring area, Campbell County, Wyoming (after Everett, 1979).

Political boundaries frequently create water management problems. Such a boundary may cross a major groundwater basin so that, for example, pollutants from an adjoining area may be entering from sources not subject to monitoring by the DMA. Clearly, such situations should be minimized as much as possible. Alternatively, cooperation among DMAs sharing common groundwater pollution problems will be essential to the success of their respective monitoring programs.

Physiographic Considerations--

The physiographic basis for selecting monitoring areas includes the recognition that groundwater basins are distinct hydrographic units containing one or more aquifers. Such basins usually, but not always, coincide with surface water drainage basins. By establishing a monitoring area related to a groundwater basin, total hydrologic inflows to and outflows from the basin are fully encompassed. This permits all pollution sources and their consequent effects on groundwater quality to be monitored. Where basins are extensive, monitoring areas become impractically large. Boundaries should then be drawn parallel to groundwater flows or where crossflow components are insignificant. Most groundwater basins in the United States have been mapped, based on hydrogeologic investigations, and information is available from State water agencies and/or the U.S. Geological Survey.

Priority Considerations--

Establishment of a national program to assess the impact of coal activities on groundwater quality will develop gradually because of administrative, budgetary, and personnel constraints. Since it is the stated intent of the EPA to rely on the States to select the areas to be monitored and to conduct the appropriate monitoring activities, any national program that evolves will, consequently, be built upon the data and information generated by these State monitoring activities.

A first consideration of a State will be to select and rank aquifers subject to the greatest pollution threat. This first level of priority ranking is a necessary starting point for application of the groundwater monitoring methodology. Rarely will sufficient data and information be initially available for anything but a gross appraisal of the threat.

To apply the methodology most effectively on a spatial basis, areas that have the largest number of identified or potential pollution sources and a high utilization of groundwater should be ranked and sectioned off as areas within which to apply the monitoring methodology. By utilizing the above two criteria in combination with the administrative and physiographic considerations previously set forth, the total area of a State can be divided into areas that may require monitoring programs.

Step 2. Inventory Potential Pollution Sources

The design of a monitoring program requires identification of the potential sources of waste disposal within an area. Important mine-related sources of contaminants are listed in Table 2-1 and classified in order of their potential for contaminating groundwater at typical mine sites. Priority lists for individual mines may differ in sequence. As indicated in Table 2-1, the sources may also be classified by whether they are most closely related to active mines, reclaimed mines, or miscellaneous contamination sources. Recommendations for monitoring active mine sources are presented in Section 3 and those for reclaimed mine sources are presented in Section 4. Recommendations for miscellaneous sources are discussed in Section 5. Sources in all three categories, however, may exist at an operating mine.

TABLE 2-1. CATEGORIES OF POTENTIAL POLLUTION SOURCES

Active Mine	Reclaimed Mine	Miscellaneous Sources
Pit water	Spoils	Mine solid wastes
Impoundments	Reclamation aids	Liquid shop wastes
Stockpiles		Sanitary waste
		Spills
		Leaks
		Solid waste from road construction
		Explosives

Step 4. Define Groundwater Usage

While Steps 3, 5, 6, 7, and 8 must be developed for each potential source of pollution, Step 4 applies to each source and need not be discussed in Sections 3, 4, and 5.

Groundwater contamination is the principal subject of concern in this study because of its effect on the usefulness of water. Water quality standards generally define water pollution in terms of its use. For each use, a standard may specify separate mandatory and recommended limits for certain physical characteristics and for concentrations of certain constituents. Thus, in evaluating the groundwater contamination potential of specific sources and development of related monitoring programs, groundwater use must be considered. Existing or potential uses most likely to be affected are those located downgradient along the paths of groundwater flow.

In addition to being a potential target of contamination, groundwater also can be a contributor to the contamination process. For example, it may act as a loading and transporting agent when in contact with spoil materials either in the unsaturated or saturated zone. Usage may also cause consumptive losses that increase dissolved solids concentrations in the remaining water. Groundwater withdrawals and uses may change the water table elevation within the spoil zone and affect the types and magnitude of pollutants being released from the spoils. For certain potential contaminants (e.g., iron sulfide minerals such as pyrite and marcasite which are below the water table), the protective presence of groundwater (with an oxygen diffusion coefficient four times less than for sulfides in air) may exclude oxygen and thereby retard the contaminating effects of sulfide oxidation (Pionke and Rogowski, 1979). Other potential contaminants, such as soluble salts, are more subject to release below the water table. While most western spoils contain sufficient soluble salts to buffer groundwater against acid production through the oxidation of pyrites, the oxidation of sulfide minerals can cause liberation of elevated levels of dissolved solids, primarily in the form of sulfates.

Ultimately, source-related pollutants may deleteriously affect various groundwater uses (e.g., municipal, agricultural, and industrial) if leachate from the source occurs. An inventory of types of uses, including the volume and location of pumping centers, is an integral component of a monitoring design and is required under the OSM Permanent Regulatory Program (30 CFR 779.15).

Shallow wells apparently are not used for domestic groundwater in the vicinity of the project mines. Almost all water used for domestic purposes is pumped from the deeper Fort Union or Fox Hills aquifers. However, shallow wells in the study area are used for agricultural water.

Most of the groundwater used on the mine sites in the study area comes from pit discharges (averaging about 100,000 gallons per day). Dust suppression is the primary use of pit discharge water, requiring up to 80,000 gallons per day during summer months. Deep wells at mine sites supply potable water for drinking, bathing, and cleanup. Potable water consumption varies depending on mine equipment, maintenance, shop cleaning, and bath house capacity.

A suitable supply of groundwater to irrigate spoils for vegetation establishment is a spoils reclamation concern. The benefits of temporary irrigation to assist in revegetation of mined areas have been studied by several researchers throughout the semiarid coal mining region (Gould, Rai, and Wierenga, 1975; Ries, Power, and Sandoval, 1976; Ries and Day, 1978; Depuit, Coenenberg, and Dollhopf, 1979; and Young and Depuit, 1981). This research indicates that temporary irrigation extends the period for successful seeding, suppresses weed invasion, enhances stand diversity, and generally assists in the establishment of perennial grasses. With the benefits that have been demonstrated by numerous researchers, temporary irrigation may become a common reclamation practice in the semiarid West. Thus, irrigation demands on existing or new wells may occur. The application of irrigation water, however, may also lead to additional percolation through the spoils, thereby increasing the potential for groundwater contamination.

Monitoring Information Needs--

A monitoring program designed to identify groundwater usage in a potential pollution area should include the following background information:

- Potable water requirements for domestic purposes
- Variations in pit discharge quantity over time
- Volume of water used for dust suppression over time

- Sources of supplemental water for dust suppression, fire protection, and coal preparation
- Volume of water used for shop, office, and sanitary purposes
- Locations of water supply wells, springs, and seepage areas relative to potential pollution sources
- Irrigation requirements for vegetation reestablishment
- Stock and wildlife watering requirements
- Volume of streamflow used for stock and irrigation downgradient of the mine area(s).

Alternative Monitoring Approaches--

Nonsampling methods--Several alternatives are available for characterizing groundwater use:

- Determine current efforts by the mine to quantify groundwater use for various needs and collect available water use data.
- Count truckloads of water sprayed on roads for dust control and obtain the capacities of the trucks.
- Obtain locations of pumping centers and uses of well water through discussions with mine personnel.
- Estimate domestic usage from the number of mine employees.
- Locate water supply wells on a base map by contacting the mine operator or the State engineer.
- Obtain data on the capacities of on-site wells.
- Estimate pumpage from power consumption data.
- Assess anticipated use of groundwater for irrigation of reclaimed land through discussions with mine personnel. (If irrigation is being used, the quantity of water can be monitored with metering devices installed in the supply lines. The volume of water needed for irrigation can also be estimated by using the Thornthwaite (1948), Blaney-Criddle (1950), or other similar method in conjunction with monthly precipitation records.)
- Obtain data on groundwater uses by discussions with mine personnel and local residents; by review of mine plans, hydrologic and geologic reports, and maps; and by field observations.

For each of the foregoing categories, some estimates of the percentages of consumptive and nonconsumptive water use are desirable.

Sampling methods--No sampling methods are required to determine groundwater usage under this step.

Recommended Monitoring Approach--

All the nonsampling methods should be employed as a function of relative levels of concern. The costs will include little or no capital expenditures and will be limited essentially to manpower rates.

SECTION 3

MONITORING RECOMMENDATIONS FOR ACTIVE MINE SOURCES OF POLLUTION

This section develops steps 3, 5, 6, and 7 of the groundwater monitoring methodology for each of the active surface coal mine pollution sources. These sources include: stockpiles (topsoil, overburden/interburden, coal, coal refuse, coaly waste, partings), pit water, and impoundments. The discussion and recommendations for impoundment monitoring are detailed and cover sedimentation ponds, evaporation ponds, sewage lagoons, and permanent impoundments. Step 8 is a mine-specific application of the methodology and is developed in Everett (1979).

STOCKPILES

Stockpiles can act as groundwater pollution sources when precipitation percolates through the stored material, dissolving pollutants and transporting them to the groundwater system. They are also subject to leaching from ponded surface waters or irrigation.

Classes of material that may be stored in stockpiles during the active mining phase are topsoil, overburden, coal, coal refuse, coaly waste, and the partings that occur between coal seams. Stockpiles may be very temporary or they may exist for the life of a mine.

Topsoil

At all the Powder River Basin coal mines, some topsoil is selectively removed and stockpiled before being replaced on top of regraded overburden. Commonly, topsoil from the first area to be mined is stockpiled because no place to use it yet exists. For example, at one mine the topsoil removed from the first area to be mined will remain stockpiled until used to cover the final area to be mined in about the year 2000. Topsoil might also be stockpiled for blending to upgrade the quality of reclamation soil cover.

Overburden

Overburden is that material lying between the topsoil and the mineable coal beds. In the study area, the mineable coal lies at or near the top of the Fort Union Formation and the overburden is sandstone, shale, carbonaceous shale, and thin or impure coal beds of the Wasatch or uppermost Fort Union Formations. In local areas, along the outcrops of coal beds, a unique rock type has been formed by the baking of shale and siltstone by burning coal beds. The baked material is commonly called scoria or clinker and may also be incorporated in the overburden. An additional type of overburden is the alluvium found in the stream valleys. It consists of gravel, sand, silt, and clay derived from the bedrock units. Overburden thickness in operating and proposed mines ranges from none at the outcrop of the mineable coal up to perhaps 300 feet as the coal beds are traced westward into the Powder River Basin. The thickness of the overburden that can be removed at a mine is based on economics and available technology.

During mining, the overburden is removed, the coal extracted, and the overburden then replaced and graded to the desired topography. Overburden removed during early development of a mine is stockpiled because there is no previously mined area in which to place it. Toxic or acid-forming material should be stockpiled separately. Materials suitable for aquifer reconstruction may also be handled separately.

Coal, Coal Refuse, and Coaly Waste

Coal, coal refuse, and coaly waste are geologically and chemically similar. Coal refuse is the fine coal and waste material removed during the coal preparation process. Coaly waste describes the thin coal seams, impure coal, and carbonaceous shale that may occur in the overburden and within the partings between coal seams. Despite their geological and chemical similarity, these materials are identified separately because they are handled differently and, therefore, have differing water pollution potentials. Coal, the commercial product, is handled carefully. It is mined soon after exposure by stripping and is not allowed to weather. After mining, it is usually processed in some manner. Common steps in coal processing include crushing, screening, and washing. Coal from Powder River Basin mines is usually only crushed. After crushing, it is temporarily stored in silos, bunkers, or open piles (used only occasionally, limiting their potential for pollution from infiltration).

Coaly waste is considered separately from the remainder of the overburden because it usually has a different type and amount of water pollution potential. Its geochemical properties also affect its potential as a soil-forming material. Such materials commonly form toxic soils and are thus segregated from the other overburden during mining. Western coaly waste commonly has elevated levels of sulfides. The oxidation of sulfides and associated dissolution of carbonate minerals can be responsible for elevated levels of TDS (totally dissolved solids, specifically sulfates). A frequent method of handling is to attempt to place the coaly waste at or near the bottom of the spoils. The State of Wyoming has two philosophies for handling coaly wastes high in sulfides. One is to bury the waste above the water table in an area where minimal deep percolation can move through the material. The second is to bury the waste in the saturated zone, thereby limiting the potential for oxidation of the sulfides (personal communication, D. Fransway of Wyoming Department of Environmental Quality, 1982). In order to selectively place the coaly waste, it may be necessary to stockpile it temporarily.

The three types of stockpiles may yield different potential groundwater pollutants. Therefore, the identification of potential pollutants (Step 3) is discussed separately for each material. The remaining Steps (5 through 7) are discussed for stockpiles in general.

Step 3. Identify Potential Pollutants--Topsoil

Potential groundwater pollutants in stockpiled topsoil may be due to (1) the natural poor quality of soils that are stockpiled, (2) fertilization and irrigation of the stockpiled soils, and (3) physical and chemical changes in the soils after they have been stockpiled for long periods of time. Poor-quality soils are generally treated as spoils.

If vegetation is not immediately established on topsoil stockpiles, they may contribute excessive sediment to sedimentation ponds. Many topsoil stockpiles are surrounded by ditches or berms to reduce the sediment problem. If the stockpiles are fertilized and irrigated, however, leaching could occur by water percolating through the root zone. Compounds of nitrogen and potassium could be potential pollutants, with nitrates being of principal concern.

Gradual physical and chemical changes may occur in stockpiles of long duration, primarily from leaching in the surface layer. Leaching of nitrates and other readily soluble salts turned over from lower soil layers may occur from mixing during stockpiling operations. If the stockpiles are deep, the lack of oxygen will result in a diminished number of microorganisms at the lower levels, particularly in the soils underlying the stockpiles. Because of the reduced oxygen availability, an increase in ammonium-nitrate could be expected in the deeper layers.

Topsoils in the Powder River Basin may contain certain trace elements that can be significant groundwater pollutants. Summary analyses of trace elements in near-surface materials in the Powder River Basin are given by the U.S. Geological Survey (Keefer and Hadley, 1976). Most trace element analyses in mining and reclamation plans use rigorous extraction procedures (e.g., organic chelates, DTPA acid method, or hot water) that remove more constituent from a soil sample than that readily available to percolating water under field conditions. The extraction methods do not remove constituent from the mineral structure but do strip ions from exchange sites, thereby indicating available plant concentrations for particular parameters (personal communication, D. Fransway, 1982). Therefore, topsoil and overburden trace element analyses that are readily available in mining and reclamation plans can be used to identify zones with high concentrations of constituents that may cause water quality problems. After these readily available analytical data have been used to identify a zone with potential to cause groundwater degradation, additional analyses using distilled water extracts are appropriate. The distilled water extracts are more representative of water soluble concentrations of constituents that may be expected in water percolating through the topsoil with the potential to reach groundwater systems. Dollhopf et al. (1979) found that the results of column leach tests produce trace metal concentrations that are generally similar to concentrations observed in spoil wells in the Colstrip, Montana area. Dollhopf et al. concluded that column leaching methods may be promising for predicting trace element concentrations in spoil groundwaters, although additional work is necessary on this topic.

Major soil series on the AMAX Eagle Butte lease were analyzed for boron, cadmium, lead, and mercury concentrations (see Table 3-1). In another analysis, boron was found to range from zero to 1.01 ppm with an average of 0.47

ppm on Sun Oil's Cordero Mine. Selenium found at the Wyodak Mine ranges from less than 0.01 to 0.06 ppm (averaging 0.01 ppm), with boron concentrations between 0.2 and 2.0 ppm averaging 0.81 ppm. Trace element analyses were not available for many of the mines.

TABLE 3-1. CONCENTRATIONS (ppm) OF TRACE ELEMENTS BORON, CADMIUM, LEAD, AND MERCURY IN SOILS ON THE EAGLE BUTTE MINE PROPERTY

Soil Series	B	Cd	Pb	Hg
Terry	0.18	0.52	1.95	0.27
Vona	0.12	0.52	1.99	0.31
Maysdorf	0.08	0.50	2.36	0.39
Renohill	0.29	0.66	2.65	0.38
Bidman	0.25	0.53	2.00	0.18
Goshen	0.48	0.57	1.81	0.32
Arvada	1.94	0.56	3.28	0.40
Shingle	0.13	0.54	2.44	0.58

Topsoil characteristics summarized in Table 3-2 for four Wyoming mines give ranges for sodium adsorption ratio (SAR), electrical conductivity (EC), and pH along with the number of samples analyzed. The SAR is defined as:

$$\frac{\mathrm{Na}}{\sqrt{(\mathrm{Ca} + \mathrm{Mg})/2}} ,$$

where the concentrations of the constituents are expressed in milliequivalents per liter. EC refers to the conductance of a cube of the saturated paste, 1 centimeter on a side and measured at 25°C. These parameters are commonly measured on saturation paste extracts that are considered close to field conditions.

Monitoring Needs--

Monitoring needs include identification and characterization of soils on the mine plan (permit) area, estimates of the locations, volumes and anticipated duration of topsoil stockpiles, and characterization of physical and chemical changes in soils that have been stockpiled for an extended period of time.

Alternative Monitoring Approaches--

A preferred monitoring approach for characterizing potential pollutants in topsoil stockpiles includes both nonsampling and sampling methods. Possible alternative approaches are given below.

TABLE 3-2. SITE-SPECIFIC TOPSOIL CHARACTERISTICS

Mine	Sodium Adsorption Ratio			Conductivity (mmho/cm)			pH			Number of Samples
	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	
AMAX Belle Ayr South	0.2	7.5	2.62	0.13	1.53	0.81	7.2	8.1	7.6	86
AMAX Eagle Butte	0.3	5.1	2.19	0.13	--	1.04	7.6	8.2	7.95	20
Sun Oil Cordero	0.18	16.18	5.62	0.13	21.3	5.68	6.2	8.2	7.6	58
Wyodak	0.5	8.9	5.0	[a]	2.18	0.052	7.3	9.2	8.4	43

Note:

[a]Data missing.

Nonsampling methods--One of the first steps is to obtain soil inventory maps for the lease area. These maps can be used to identify soils that may be stockpiled and their chemical characteristics. Plans for topsoil removal can be compared with soil inventory maps for a closer estimate of the future volume of stockpiled topsoil and the expected life of individual stockpiles.

The volume of existing stockpiles can be estimated in three ways: (1) from mine engineering and production records and mine plans, (2) the stockpiles can be measured and the volumes computed, and (3) aerial photography. Mine records may also yield information on the use of irrigation and fertilizers on stockpiles.

The amounts of potential pollutants in the stockpiles can be estimated from the volume of stockpiled material and information on potential pollutants in the topsoil.

The costs include:

- Labor: review of soil maps; computation of stockpile volume from measurements; and review of aerial photographs, mine records, and plans.
- Operation: any possible field transportation.

Sampling methods and method of analyses--Existing soil chemistry information should be sufficient to identify topsoil with the potential for causing groundwater degradation. If high concentrations of a constituent are found using the standard extract methods, additional analyses using distilled water extracts can be used to better characterize amounts of the constituent available in water-soluble form to contaminate groundwaters.

Topsoil stockpiles that remain in place for extended periods of time (e.g., a year or more) may undergo physical as well as chemical changes. To evaluate these, stockpiles should be sampled at 2-foot vertical intervals at more than one point per acre of stockpiled material. Samples should be analyzed annually for:

- pH (determination on paste)
- Electrical conductivity (EC; millimhos per centimeter on saturated extract)
- Saturation percentage
- Calcium (ppm)
- Magnesium (ppm)
- Sodium (ppm)
- Sodium adsorption ratio (SAR)
- Boron (ppm)
- Nitrogen (sum of nitrate-nitrogen [NO_3-N] and ammonium-nitrogen [NH_4-N] in soil)
- Phosphorous (ppm)
- Potassium (ppm)
- Trace metals (ppm)
- Total salts (ppm).

Costs of the sampling approach will depend upon the areal extent and volume of stockpiled topsoil. The types of monitoring costs have been identified and are:

- Labor: review of soil maps; interview of mine personnel; and sample handling, preparation, quality control, etc.
- Operational costs: chemical analysis of samples and air freight, refrigeration, packing, etc. for samples.
- Capital costs: containers, labels, chemicals, etc. for samples and hand-driven soil sampler.

Recommendations--

A nonsampling approach is often preferable to the sampling approach because it may indicate that further monitoring activities are unwarranted. Where stockpiles have been in place for a year or more, sampling methodology is the best approach. This approach will enable assessment of physical and chemical changes occurring over time to determine if pollutants are present in amounts that warrant more intensive or continued monitoring. The use of aerial photography is not recommended for mines with small numbers of closely spaced stockpiles due to the expense involved.

Step 3. Identify Potential Pollutants--Overburden and Interburden

As with topsoil, a potential water pollutant in overburden is soluble salts. For example, the soluble salt content of six overburden samples from the Sun Oil Company Cordero mine ranged from 0.04 to 0.88 percent by weight (Dames and Moore, 1974). Using these values and an assumed dry weight of 1.5 tons per cubic yard for overburden, there would be from 1.2 to 26.4 pounds of soluble salt per cubic yard. Because an acre-foot of overburden contains 1,613 cubic yards, each acre-foot of overburden would contain 1,936 to 42,580 pounds of soluble salts.

Table 3-3 summarizes analyses of conductivity, sodium adsorption ratio, cation exchange capacity, pH, and trace elements from cores of the overburden taken from selected mines. Trace element analyses are also available for the ARCO Black Thunder mine and the Wyodack mine. The rigorous extraction procedures (as mentioned for topsoils) generally show higher trace element concentrations than are water soluble and available for transport into groundwater systems. The trace element data, obtained using plant-available extraction techniques, can be used to identify zones with higher concentrations of trace elements, which may have potential for groundwater degradation. Zones found to have higher concentrations of a particular element should be reanalyzed using a distilled water extract to better characterize the amount of constituent available to move to the groundwater system.

Maximum electrical conductivity (EC) values range from 4.2 to 8.0 millimhos per centimeter (mmho/cm) throughout the study area. Values less than 8.0 mmho/cm indicate only moderately saline conditions (Wiram, no date). High EC values are found for samples taken within 5 feet of the surface on the Belle Ayr South Mine. For deeper overburden, salt concentrations are usually less than 2.0 mmho/cm which is considered to be insignificant (Wiram, no date) and would have negligible effect on plant growth.

The major anions responsible for the observed EC values on the Eagle Butte lease are, in order of abundance: sulfate, chloride, bicarbonate, and nitrate. The major source of sulfate is gypsum ($CaSO_4$-$2H_2O$) and epsomite ($MgSO_4$-$7H_2O$). Palmer and Cherry (1979) describe two processes, including the oxidation of organic water (production of CO_2) and dissolution of carbonate minerals, responsible for the presence of HCO_3 in groundwaters. Soluble nitrates may be formed by the nitrification of exchangeable ammonium nitrogen (Power et al., 1974).

High SAR values were also found in the uppermost 5 feet. The maximum value was 17.6. For deeper overburden, SAR values averaged 3.5, indicating that the clay minerals are saturated with calcium and magnesium. Shales and mudstones, in general, were found to have slightly higher SAR values than associated sandstones.

Almost all of the overburden samples were found to have a pH greater than 7, with the values ranging from 3.6 to 8.7.

TABLE 3-3. SITE-SPECIFIC OVERBURDEN CHARACTERISTICS

Mine	Number of Samples	Conductivity (mmho/cm)			SAR			CEC[a] (meq/100 g)			pH			Elements[b] (ppm)								
		Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg	Cd	Hg	Pb	Zn	Ni	Cu	S	As	Se
AMAX Belle Ayr South	74	--	6.2	--	--	17.6	3.5	--	30.0	16.8	5.3	8.2		0.23	0.08	1.0	--	--	--	--	--	--
AMAX Eagle Butte	92	--	6.5	--	--	--	3.3	12.8	36.0	27.5	5.0	8.5		0.17	0.05	0.43	--	--	--	--	--	--
ARCO Black Thunder	41[c]	--	--	--	--	--	--	--	--	--	--	--		3.44	0.12	35	--	--	33.8	--	0.8	--
Carter North Rawhide	11	0.7	4.2	1.9	--	--	--	13.0	33.0	--	7.4	8.7		--	--	--	--	--	1.7	168	--	--
Kerr-McGee Jacobs Ranch	55	0.5	5.5	--	--	--	--	11.0	32.0	22.7	7.8	8.4		--	--	--	--	--	0.88	167	--	--
Sun Oil Cordero	89	0.5	8.0	--	0.3	7.2	--	3.9	48.4	--	3.6	--		0.1	0.07	4.3	14.8	2.1	--	--	--	--
Wyodak	7[c]	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	--	0.47	487	--	0.1

Notes:

[a] Cation exchange capacity.

[b] Average concentrations.

[c] Trace element analysis only.

Five overburden samples from Belle Ayr South were found to have a total sulfur content greater than 1.0 percent, with the others rarely exceeding 0.3 percent. Of the five samples, two contained fine-grained pyrite and others had large amounts of gypsum and carbonaceous matter. Gypsum crystals (selenite; $CaSO_4$-$2H_2O$) and soluble sulfate salts are the major sources of sulfur in the overburden. Sulfate concentrations were found to range from 20 to 40 meq/liter, primarily in the form of selenite.

The overburden trace element analyses of Table 3-3 show cadmium concentrations of 0.1 to 3.44 ppm and mercury concentrations of 0.05 to 0.12 ppm. Arsenic found at Black Thunder ranged from less than 0.05 to 7.75 ppm, averaging 0.8 ppm. Selenium was found in concentrations less than 0.1 ppm for all samples taken at Wyodack.

Chemical analyses of partings and interburden have been more limited than those for overburden, but those that have been done tend to confirm that the same elements are present.

The U.S. Bureau of Land Management (1974) states that chemical analyses were run on two samples of parting material between coal seams at the Carter North Rawhide mine. Electrical conductivity values were found to be 2.4 and 0.8 mmho/cm. Both parting samples were found to be acidic, with pH values of 4.9 and 6.8. Values for sulfur content were 200 and 39 ppm and the copper content was 8.2 and 1.6 ppm. Recommendations for calculating net acidity (potential acidity and neutralization potential) can be found in Section 4.

According to the U.S. Bureau of Land Management (1974), chemical analyses were run at the Kerr-McGee Jacobs Ranch mine on three samples from the parting between the Upper Wyodak and Lower Wyodak 1 coal seams. All three samples were taken from a single drill hole and showed little variation. The average electrical conductivity value was 0.83 mmho/cm. All of the samples had basic pH values of 7.9, 8.1, and 8.2. The sulfur content in all three samples was greater than 200 ppm. The average copper content was 1.57 ppm.

Existing monitoring on the AMAX Belle Ayr South lease includes in-place overburden samples that have been collected from eight drill holes on a 1/2-mile grid over three-fourths of the mining area. In these holes, the upper 10 feet have been sampled on 1-foot intervals and the remainder of each hole has been sampled at 10-foot intervals to the top of the coal. Electrical conductivity measurements indicate the materials in general to be slightly saline. Sodium adsorption ratios taken in the upper 5 feet also indicate moderately saline soils.

Monitoring Needs--

Data related to undisturbed overburden materials may be useful in characterizing overburden stockpiles; however, it will also be necessary to monitor stockpiled overburden materials to determine if any appreciable changes in their overall composition have resulted from mining and stockpiling. Monitoring needs include the chemical composition of in-place overburden using distilled water extracts; the volume, composition, and expected life of overburden stockpiles; and changes that occur in the overall chemical makeup of stockpiled overburden from exposure to a new environment.

Alternative Monitoring Approaches--

A recommended monitoring approach for characterizing potential pollutants in overburden stockpiles can be selected from the following nonsampling methods or sampling methods.

Nonsampling methods--The primary nonsampling method is to obtain, review, and interpret the existing data on the chemical characteristics of the in-place overburden. The next step is to determine the volume of overburden stockpiled for any appreciable time (1 year or more). From this information, the chemical nature and volume of potential pollutants in the stockpiled overburden can be estimated. The use of low-altitude aerial photography is inappropriate because of is cost. If adequate, engineering and production records for the mining operation can be used to estimate the volume and duration of the material stockpiled.

The costs of this approach are for labor only; they include:

- Review of existing data on in-place overburden (e.g., water well or core hole lithologic logs, geophysical logs, core sample analysis, etc.)
- Review of engineering production records or aerial photographs for volume determination
- Review of mine engineering and production records for determining estimated stockpile durations.

Sampling methods and methods of analysis--Overburden stockpiles expected to remain in place for a year or more should be sampled to determine if exposure causes any changes in their overall chemical makeup. For a reconnaissance level investigation, samples can be obtained at 10-foot intervals vertically through the stockpile. One sample hole per 10 acres of surface area should be sufficient. If serious chemical changes are documented, such as high levels of nitrates resulting from oxidation of ammonia (NH_4+), greater sampling intensity is warranted. Sampling densities on 30-meter grids have been used for research level efforts where the intent was to locate inhibitory zones in spoil materials (Dollhopf et al., 1981). Unless some means is devised to hold the hole open while taking the samples, sampling the material will most likely be difficult because of its unconsolidated nature. All samples should be analyzed for the parameters listed in Table 3-4.

The costs for this approach include:

- Labor: compilation of volumetric and chemical data from field and laboratory analysis; sampling of new and old (more than 1 year) stockpiles to determine chemical change; and sample handling, preparation, quality control, etc.
- Operational: chemical analysis; air freight, refrigeration, packing, etc.; and field transportation.

TABLE 3-4. MONTANA DEPARTMENT OF STATE LANDS LIST OF PARAMETERS FOR SOIL AND OVERBURDEN MONITORING

Quantity	Methods of Analysis[a]
pH	Paste
Conductivity	Saturation extract
SAR	Saturation extract
Texture	Hydrometer
Boron	Distilled water extract[b]
Cadmium	Distilled water extract[b]
Copper	Distilled water extract[b]
Iron	Distilled water extract[b]
Lead	Distilled water extract[b]
Manganese	Distilled water extract[b]
Mercury	Distilled water extract[b]
Molybdenum	Distilled water extract[b]
Nickel	Distilled water extract[b]
Selenium	Distilled water extract[b]
Zinc	Distilled water extract[b]
Ammonium-nitrogen[c]	Distilled water extract[b]
Nitrate-nitrogen[c]	Distilled water extract[b]

Notes:

[a] The recommended methods of analysis are based on recent research for determining potential impact to groundwaters and are not necessarily recommended by the State of Montana.

[b] Possibly using leach columns.

[c] The significance of ammonium and nitrate stems from the water pollution potential of nitrate. The Federal drinking water standard is 10 ppm nitrate-nitrogen and a recommended maximum concentration for livestock is 100 ppm nitrate plus nitrate-nitrogen. Ammonium can be biologically oxidized to nitrate if conditions are suitable.

- Capital: sample containers, labels, chemicals, preservatives, etc., and hand-driven soil sampler.

Recommended Monitoring Approach--

The preferred approach for monitoring the potential pollutants in stockpiled overburden is:

1. Review existing data on chemistry of in-place overburden.
2. Determine the volume of overburden stockpiled by direct measurement.
3. Sample the stockpile at 10-foot vertical intervals (a minimum of two samples per location, with one hole every 10 acres).
4. Analyze annually for parameters listed in Table 3-4. Overburden should not be analyzed using DTPA acid techniques; column leach extracts have provided concentrations most similar to spoil groundwaters (Dollhopf et al., 1981). Analyses of column leach extracts using distilled water are recommended at this time although more research is needed in this area.

Step 3. Identify Potential Pollutants--Coal, Coal Refuse, and Coaly Waste

One of the characteristics of the project area coals is the low sulfur content. Elevated concentrations of sulfides and organic sulfur, however, are commonly associated with carbonaceous materials such as coal stringers, carbonaceous shale, and top or bottom coal that is wasted (personal communication, N. Harrington, Montana Department of State Lands; D. Fransway, Wyoming Department of Environmental Quality; and J. Rogers, Front Range Laboratories [Fort Collins, Colorado]). Palmer and Cherry (1979) acknowledge the oxidation of pyrites and organic sulfur and the subsequent dissolution of carbonate minerals as one of the primary reactions influencing spoil groundwater quality changes. The concern in the West is not acid spoil waters but, rather, significantly elevated TDS. More specifically, sulfates are increased as a result of this process and this, coupled with sulfates already present in the spoils, can significantly increase spoils sulfate concentrations to the point that waters will not be suitable for postmining stock or domestic uses. Section 4 and Appendix B (taken directly from Smith et al., 1974) contain a discussion of calculations used to predict the net acid-neutralization potential of spoils when acid waters are a real concern. Acid that is found might also dissolve some trace metals before it is neutralized although, as the pH is neutralized, metals soluble in acid conditions will precipitate. According to the U.S. Geological Survey (1975), a representative coal sample at the AMAX Belle Ayr South mine had a sulfur content of 0.6 percent. Sulfate content was given as 0.02 percent, pyrite sulfur as 0.17 percent, and organic sulfur as 0.44 percent.

Coal, coal refuse, and coaly waste probably contain some soluble salts. However, no analysis of the soluble salt content of these materials has been found in the literature or in unpublished reports. The soluble salts are expected to be principally in the form of gypsum crystals or similar minerals formed in open fractures. Intergranular pores are not present in the coal and coaly strata as they are in the rest of the overburden.

Sulfur is universally found in coal and carbonaceous strata but in different forms and varying amounts. The two general forms of sulfur that occur in and with coal are inorganic and organic. Inorganic sulfur occurs primarily as pyrite or marcasite, which are both iron disulfide (FeS_2). As far as is known, no studies have been made of the amount and fate of acid formed in Powder River Basin strata as a result of coal strip mining.

Sulfur- and iron-oxidizing bacteria are present at existing mines, however, and probably do generate small amounts of acid. Olson and McFeters (1978) found Thiobacillus ferrooxidans at numerous sites at the Decker (Montana) and Big Horn (Wyoming) mines. They concluded, however, that acid produced by T. ferrooxidans is quickly neutralized by bicarbonate in the mine waters and therefore is not evident in mine effluents.

A number of measurements have been made of the trace elements in Powder River Basin coals. Keefer and Hadley (1976) present a summary of analyses of 15 coal samples from Wyodak mine and 11 samples from Belle Ayr mine. A few trace elements are present in coals in amounts greater than in the overburden and the earth's crust as a whole, but these trace elements have not yet been identified as actual water pollutants. Table 3-5 summarizes trace element and sulfur content of coal samples.

Monitoring Needs--

All mining companies analyze coal seam samples before mining. Usually, the proximate analyses include moisture content, volatile matter, fixed carbon, ash, Btu, softening, grindability, and specific gravity. The ultimate analyses may also include hydrogen, carbon, nitrogen, oxygen, chlorine, sulfur, sulfate, pyrite, and organic content. Ash analyses should include the following:

Al_2O_3	Fe_2O_3	MgO	SiO_2	TiO_2
P_2O_5	SO_3	Na_2O	CaO	K_2O

These elements have also been measured in Powder River Basin coals. Sufficient information is available to characterize coals in the project area in terms of the potential pollutants they contain, except soluble salts. This does not appear to be the case for coaly waste; no records have been found to indicate any attempts to characterize it. This waste is usually lumped with the overburden core analysis which requires sampling at discrete depths to the coal. Stockpiles of coaly waste should be sampled to determine if, in fact, soluble salts are present in sufficient amounts to present a problem.

Uncertainty exists about the location of coaly waste stockpiles and methods of disposal for this material on most mining sites. In many instances, it is mixed indiscriminately with overburden materials and backfilled. Stockpiles of coaly waste need to be located and grab samples acquired for chemical analyses to identify any potential groundwater pollutants.

TABLE 3-5. SULFUR AND TRACE ELEMENT CONCENTRATIONS IN COAL SAMPLES

Mine	Sulfur (percent)	Average Trace Elements (ppm)						
		Cd	Hg	Pb	As	Se	U	Cu
AMAX Belle Ayr South[a]	0.25-0.6[e]	0.1	0.13	2.7	2.5	1.1	1.0	--
AMAX Eagle Butte[b]	0.14-1.0[e]	--	0.1	1.0	1.1	0.31	1.1	--
ARCO Black Thunder[c]	*0.09-0.59*[e]	*0.36*	0.19	11.62	0.15	--	1.5	--
Carter North Rawhide[c]	0.28-0.52[e]	--	0.1	1.0	1.1	0.13	1.09	--
Kerr-McGee Jacobs Ranch[c]	1.06	<0.001	<0.001	--	0.02	--	--	0.002
Sun Oil Cordero[d]	0.30	0.66	0.1	2.1	2.1	0.44	--	--
Wyodak[c]	0.59	0.1-0.16[f]	0.09	9.12	1.0-2.0[f]	0.86	0.88	--

Notes:

[a] U.S. Geological Survey (1975).

[b] U.S. Geological Survey (1976a).

[c] U.S. Bureau of Land Management (1974).

[d] U.S. Geological Survey (1976b).

[e] Range of sulfur concentrations.

[f] Range of trace element concentrations.

Alternative Monitoring Approaches--

Alternative sampling and nonsampling approaches for monitoring the potential pollutants in coal, coal refuse, and coaly waste are discussed below.

Nonsampling methods--A primary nonsampling method is to determine the volume of coal, coal refuse, and coaly waste stockpiled. The manner in which these materials are stockpiled will, to a large degree, determine if they present a threat to groundwater quality. For example, coal stored in open bunkers with concrete floors may not present a problem. Two alternatives for estimating the volume of these materials are: (1) directly measure the areal extent of the stockpiles and periodically update this information, or (2) work directly from mine engineering and production reports. Any available data on the chemical characteristics of the stockpiled materials can be obtained from mine operators and used to estimate the total volume of potential pollutants in the stockpiles.

The labor costs of this approach include determining the method and duration of stockpiling from mine engineering and production records, and determining potential coal pollutants from existing chemical data.

Sampling methods--If the stockpiles are exposed to the elements, some weathering and possible leaching may take place. Most weathering will occur at or near the surface of the stockpiles. Grab samples can be taken at a few locations on the stockpiles. The samples should be analyzed using distilled water extracts for the following:

Ag
Cu
Ni
Pb
Cd
Zn
Se
Mn
Cr
Hg
B
Be
As
Ge
V
Mo
U
F

These elements should be analyzed with an accuracy of ±20 percent of the actual population concentrations. Therefore, at least three replications will be necessary for each stockpile. More may be required to achieve an acceptable accuracy.

Analyses--

The analysis should include all identifiable trace elements, although only the foregoing 18 require an accuracy of ±20 percent.

Spark-source mass spectrometry is recommended as the most accurate method. Other methods, such as neutron activation analyses, may also be used. However, wet chemical methods are satisfactory and are used by most laboratories. Analyses by wet chemical methods should be performed as follows:

Ag - atomic absorption spectrometry
Cu - atomic absorption spectrometry
Ni - atomic absorption spectrometry
Pb - atomic absorption spectrometry

Cd - atomic absorption spectrometry
Zn - atomic absorption spectrometry
Se - atomic absorption spectrometry
Mn - atomic absorption spectrometry
Cr - atomic absorption spectrometry
Hg - double gold amalgam flameless atomic absorption
B - emission spectrometry
Be - emission spectrometry
As - colorimetric
Ge - colorimetric
V - colorimetric
Mo - colorimetric
U - fluorometric
F - specific ion electrode.

Additional analyses will include hydrogen, carbon, nitrogen, oxygen, chlorine, sulfur, and sulfate pyrite.

Annual measurements should be adequate to follow any changes in the chemical characteristics of stockpiled coal, coal refuse, or coaly waste. Stockpiling of coal for such long periods of time will be unusual. Stockpiles usually will be augmented or depleted on a regular basis.

The cost of this monitoring approach includes:

- Labor: determining method of stockpiling, location, and volume from field surveys; collection of grab samples; and sample handling, preparation, quality control, etc.

- Operational: chemical analyses of grab samples; air freight, refrigeration, packing, etc.; and field transportation.

- Capital: sample containers, labels, chemicals, etc., and hand-driven soil sampler.

Recommendations--

The preferred monitoring approach is to determine the volume of stockpiled material by direct measurement and use this information, along with available data on the chemical characteristics of the stockpiled materials, to estimate the volume of potential pollutants in the stockpiles. Samples should be collected and analyzed as needed to fill data gaps.

Step 5. Evaluate Infiltration Potential

The purpose of determining the infiltration potential of a source is to quantify the volume of water and associated pollutants moving into the underlying vadose zone. Information must be obtained on precipitation, irrigation rates, runoff rates, evapotranspiration, and soil water content at field capacity and at the permanent wilting point. This information can be used for a water balance calculation to determine if significant amounts of water are percolating through the stockpiles to cause groundwater degradation.

Monitoring Needs--

A need exists to determine if water can move through stockpiles in sufficient quantities to carry potential pollutants into the vadose zone. Although infiltration from precipitation will be high to moderately high on the loose materials of stockpiles, infiltrating water is unlikely to penetrate deeply enough under the natural precipitation regime or irrigation to contribute significantly to groundwater. This must be established, however, particularly for stockpile areas near natural stream channel areas with shallow groundwater.

Deep percolation of water (below the root zone) is the mechanism necessary to transport pollutants from stockpiles. McWhorter (personal communication, 1981) recommends using a water balance method to calculate the amount of water moving through stockpiles. The following method is recommended as a calculation to determine if significant volumes of water are available for transport of pollutants (before a detailed field monitoring program can be justified).

The surface water balance on a stockpile can be expressed as:

$$P - Q = I \tag{3-1}$$

where P = precipitation

Q = direct runoff

I = infiltration.

Precipitation (P) values can be obtained from climatological records. Determination of Q using the Soil Conservation Service curve number approach is recommended for individual storms where only those storms exceeding the initial abstraction produce a value for Q. Infiltration capacity as determined from double-ring infiltrometer tests is useful for assisting in the determination of initial abstraction by the SCS procedure. (This is done directly by curve number.) Experience with data from Colorado and Arizona indicates that the number of storms exceeding the initial abstraction that must be considered is generally less than 10. The value of I determined from the above calculation is considered to be the temporal distribution of infiltration into stockpiles.

A monthly water balance for the root zone, assuming an average precipitation year, can be calculated by:

$$I - Et - W + \Delta S = 0 \tag{3-2}$$

where I = infiltration (from equation 3-1)

Et = potential evapotranspiration

W = percolation below the root zone

ΔS = the change in soil water storage in the root zone.

Determination of potential evapotranspiration (Et), assuming water availability is not limiting, can be done using the Blaney-Criddle (1950) equation. The Blaney-Criddle equation is considered more acceptable for arid or semiarid regions than the Thornthwaite (1948) method, which is generally used for humid and subhumid regions. The actual evapotranspiration (Eta) is calculated as part of the water balance in the following example, where Eta is limited by the amount of water available each month in the soil profile. The volumetric water content at permanent wilting and at field capacity is obtained from laboratory measurements. Calculation of the maximum available water capacity that can be stored in the soil profile is:

$$AWC = (Ofc - Opw)\ D \tag{3-3}$$

where AWC = maximum available water capacity

Ofc = volumetric water content at field capacity

Opw = volumetric water content at the permanent wilting point

D = depth of the root zone.

The change in soil water storage (ΔS) can also be determined by accounting for all the inputs and outputs of moisture from the soil profile according to the following example. The parameter of greatest concern, percolation below the root zone (W), is the end product of the calculations in the following example. The volume of moisture lost to deep percolation is the amount of water available to carry pollutants from stockpiles.

A. Determine the maximum available water capacity (AWC) when the difference between the field capacity and permanent wilting point water contents (Ofc - Opw) is known to be 0.7 in/in with a root zone (D) 36 inches deep.

$$AWC = (0.07\ \text{in/in})\ (36\ \text{in}) = 2.52\ \text{inches.} \tag{3-4}$$

B. Calculate the amount of water lost to deep percolation (W) for each month.

	1	2	3	4	5	6	7
	AW	Deficit	I	Et	Eta	ΔS	W
April	0.40	2.12	4.04	1.52	1.52	+2.12	0.40
May	2.52	0	4.81	3.26	3.26	0	1.55
June	2.52	0	1.23	4.87	3.75	-2.52	0
July	0	2.52	1.29	5.23	1.29	0	0
August	0	2.52	1.90	4.01	1.90	0	0
September	0	2.52	1.52	2.28	1.52	0	0
October	0	2.52	1.49	1.50	1.49	0	0
November	0	2.52	0.40	0	0	+0.40	0
			16.68		14.73	0	1.95

where 1. AW = the initial available water stored in the root zone at the beginning of each month. The initial value at the beginning of the growing season (April) can be assumed to be zero, or the residual moisture stored from the previous year may be used. In the example, the value (0.40) calculated for ΔS for November was used for the April initial available water value.

2. Deficit = the net storage capacity remaining in the root zone after all inputs and losses have been accounted for, for the month. The deficit cannot exceed the value of the maximum available water capacity, AWC (2.52 inches in this example).

3. I = infiltration values determined from previous calculation (equation 3-1).

4. Et = potential evapotranspiration determined from previous calculation.

5. Eta = actual evapotranspiration allowed, limited by moisture availability in the root zone.

6. ΔS = change in storage in the root zone. This is the net gain or loss of moisture for the months that have been accounted for.

7. W = amount of water lost to deep percolation that is available for transporting pollutants from the stockpile. Percolation can occur only when the initial moisture in the root zone (AW) plus the amount of water gained by infiltration (I) exceeds the current moisture deficit plus the actual evapotranspiration for the month.

Alternative Monitoring Approaches--

Laboratory determinations of saturated conductivity on disturbed samples are of doubtful value for indicating infiltration characteristics. Infiltrometer tests in the field, however, are useful for establishing relative rates of water penetration at the soil surface. A double-ring infiltrometer can be used for field tests on the stockpiles. Data can be analyzed to determine the probable penetration of water under natural rates of precipitation or under applied irrigation schedules. Several methods are available for determining infiltration under conditions of unsteady application of water at the surface. These methods can be used with climatic records to determine maximum expected depth of water penetration. In addition, laboratory determinations of moisture content at field capacity and permanent wilting point are necessary for the water balance calculation.

Costs include labor for conducting and analyzing the infiltration tests and capital costs for infiltrometers. Standardized methods are available for determining soil moisture contents at field capacity and at the permanent wilting period. Laboratory costs are associated with this determination.

Recommendations--

Double-ring infiltrometer tests can be run. No fewer than three runs should be made on each stockpile, and more should be made if considerable variation is found in the materials.

Step 6. Mobility of Potential Pollutants in the Vadose Zone

Potential pollutants for stockpiled material include inorganic chemical, organic chemical, and radiological types. The major inorganic chemical groundwater constituents that can enter the vadose zone are calcium, magnesium, sodium, potassium, carbonates, chlorides, sulfates, boron, fluoride, iron, manganese, nitrogen oxides, and phosphorous oxides. Inorganic trace elements are barium, chromium, copper, lead, lithium, nickel, strontium, vanadium, zinc, zirconium, arsenic, cobalt, cadmium, mercury, beryllium, selenium, molybdenum, titanium, bromine, tin, tellurium, and silver. Organic chemical compounds (total organic carbon, or TOC) can also migrate through the vadose zone, as can the radiological compounds of uranium, thorium, and radium-226. Organic acids can be expected in the vadose zone and their presence is highly important. The organic acids mobilize trace metals through chelation, thus increasing their potential migration in the hydrologic system.

Of the major inorganic chemical constituents, sodium and chloride are relatively mobile. Calcium, magnesium, bicarbonate, and sulfate may be precipitated in the vadose zone. These and other constituents may be dissolved from minerals by water percolating through the vadose zone. Nitrate is relatively mobile and iron and manganese are generally immobile under aerobic conditions. The bacteriological content of water leaving the vadose zone should be low due to pollutant attenuation in the vadose zone.

At least three major sources of data can be used to assess trace element mobility in the vadose zone. First, numerous leaching studies have been performed for specific elements applied to specific soils. Second, the general geochemical behavior for many trace elements in natural water systems is fairly well defined. Third, the occurrence of selected trace elements in groundwater is generally known.

Keeney and Wildung (1977) summarize soil interactions with trace metals. Fuller (1977) presents a detailed discussion of trace element mobility in soils. He states that numerous factors control pollutant mobility but, in general, the following are most significant:

- Soil texture or particle size
- Pore space distribution in the soil
- Content and distribution of iron, aluminum, and manganese oxides and hydroxides in the soil
- pH of the soil and percolating waters
- Oxidation-reduction potential in the soil
- Organic matter content of soils and percolating waters
- Concentration of trace elements.

Selenium was found to be relatively mobile under aerobic conditions such as might be present in the vadose zone. Iron, zinc, lead, copper, and beryllium were moderately mobile. Arsenic, cadmium, chromium, and mercury were slowly mobile.

Hem (1970) discusses the occurrence of a number of trace elements in natural waters. Beryllium is generally not present in dissolved form in such waters because of its low solubility. Strontium contents are greatly limited by sulfate contents as high as those in the groundwater of the Gillette area. Barium can also be adsorbed by metal oxides or hydroxides and, thus, generally occurs in only small concentrations in groundwater. Titanium is not present in high concentrations in natural water because of the low solubility of its oxides and hydroxides. Vanadium appears to be soluble in groundwater under anaerobic conditions and may be present in significant concentrations if a source is present.

Numerous instances of chromium contamination of groundwater have been documented. The anionic species are apparently relatively stable in many groundwater systems. Molybdenum is predominantly present in the anionic form in groundwater. There appears to be no effective solubility control over molybdenum concentrations and, thus, large values may be found if a source is present. Cobalt content in groundwater is likely controlled by manganese or iron oxides and hydroxides and generally is low in groundwater. The general geochemical behavior of nickel is similar to that of cobalt.

The solubility of copper oxide and hydroxy-carbonate minerals tends to limit the content of copper in groundwater to low values. Silver content is limited by the solubility of silver oxide and silver chloride. In dilute aerated water, the equilibrium concentration of silver should be less than 0.01 ppm. Concentrations of zinc exceeding 1 ppm can be in groundwater. Cadmium contents in groundwater are generally very low. However, some cases of cadmium contamination have been documented for groundwater. Very few natural waters contain detectable concentrations of mercury.

Lead content is controlled by bicarbonate and sulfate contents. Lead sulfate is relatively insoluble, particularly in aerobic situations. Arsenic can be present in the anionic form over the pH range of most natural waters. Numerous occurrences of arsenic in groundwater under anaerobic conditions have been documented. The sorption of arsenate on ferric hydroxide or other active surfaces is likely an important factor, limiting arsenic contents in natural waters. The stable form of selenium in aerobic groundwater is the anion form but little information is available on selenite solubility. Bromide has a geochemical behavior similar to chloride and, thus, can occur in relatively high contents in groundwater.

Groundwater quality studies throughout the United States indicate that the trace elements chromium, vanadium, arsenic, cadmium, selenium, molybdenum, and bromine have been found in high concentrations in certain geohydrologic situations. All of these elements readily form anions in the soil-groundwater system and may be mobile in the vadose zone. Studies of hazardous waste disposal summarized by the U.S. Environmental Protection Agency (1976) indicate that the results of soil-leaching studies are consistent with these observations. These constituents should thus be given priority over other trace elements in a monitoring program.

Organic chemicals may move with percolating water through the vadose zone. However, the organic chemicals to be expected in water that contacts materials such as coaly waste have not been well defined. Leenheer and Huffman (1976) have proposed a classification scheme for organic solute characterization. The scheme begins with dissolved organic carbon and is further divided on the basis of soluble sorption and acid-base characteristics. Little is known about the mobility of the organic chemical fraction of the stockpile wastes.

Monitoring Needs--

Information on the mobility of pollutants in the vadose zone within or beneath present or future topsoil and overburden stockpiles is not currently available. A need exists to first determine if water is moving in significant quantities through the stockpiles according to the water balance calculation recommended previously. If so, monitoring those pollutants that contribute contaminants in excess of background levels will be necessary.

Alternative Monitoring Approaches--

The greatest amount of water movement in the vadose zone will occur as unsaturated flow. Although the soil surface may become saturated after heavy precipitation or prolonged irrigation, subsequent movement will occur at pressures less than atmospheric along gravitational and soil matrix potential gradients. One way of documenting unsaturated flow is through the installation of neutron probes in the stockpile. These could extend several feet into the spoils or underlying native soil. Monthly measurements could be made with the neutron probe and more frequently after heavy precipitation events or extended irrigation.

Tensiometers can be installed to measure pressure differentials with depth and thereby determine the rate and volume of flow. Under ideal conditions, tensiometers are only effective at moisture contents equivalent to negative pressure of less than 1 bar.

Porous cups installed within the stockpile at the same depths as the tensiometers can be used to extract soil solution to test for pollutants if the moisture content is sufficiently high. The cups will fail to function at -0.8 atmosphere of soil-water pressure. Samples can initially be analyzed (using distilled water extracts) for calcium, magnesium, sodium, potassium bicarbonate, chloride, sulfate, phosphate, silica, ammonia-nitrogen, nitrate-nitrogen, total nitrogen, pH, and electrical conductivity. Subsequent monitoring can be limited to the constituents that appear to exceed 20 percent of the background levels.

Costs for Step 6 include labor costs for conducting and analyzing neutron probe measurements; operational costs for installing access tubes; and capital costs for the neutron logger, steel pipe, and miscellaneous materials for construction of the access tubes.

Recommendations--

Appreciable quantities of water are unlikely to flow through stockpiled materials, even with irrigation. This concern can initially be evaluated by the water balance calculation. The results can be calibrated by conducting field infiltrometer tests. If little water movement is found, monitoring will not be necessary. If appreciable water movement is indicated, then monthly measurements with a neutron probe and the alternative methods can be implemented at a later date. The monitoring methods will document the occurrence of deep percolation and the associated quality of the leachate. These methods are not sensitive enough for determining volumes of water percolating through the stockpiles.

Step 7. Mobility in the Saturated Zone

The general purpose of this step is to measure or estimate the attenuation of source pollutants during migration in the zone of saturation. The pollutants of concern are those that have not been completely attenuated during movement through the vadose zone. Some constituents in liquids moving through all or part of the vadose zone may be substantially attenuated. Numerous pollutants, however, will likely be picked up by the percolating water and become introduced into the saturated zone. Once in the saturated zone, the mobility of these pollutants depends greatly on the aquifer transmissivity, porosity, and the hydraulic gradient.

King (1974) notes that hydraulic gradients in the more permeable aquifers of the Gillette area range from 10 to 25 feet per mile and for consolidated rock aquifers are probably about 40 to 50 feet per mile. The University of Wyoming (1976) reported on extensive groundwater monitoring at ARCO's Black Thunder mine. The hydraulic gradient for the coal aquifer ranges from 15 to 40 feet per mile.

Porosities for different aquifer materials are not well known. However, an independent analysis of groundwater flow rate can be obtained from the results of carbon-14 age dating of groundwater at Black Thunder mine. Ages in the range of 11,000 to 34,000 years for groundwater within several miles of the recharge point indicate very slow travel times, in the range of only several feet per year. Assuming a porosity of 0.10 for fractured consolidated rock, a groundwater flow rate of about 35 feet per year is calculated, based on average values for transmissivity and hydraulic gradient.

The rate of groundwater flow in the consolidated rock aquifers implies that polluted groundwater entering these aquifers would generally move very slowly. Thus, monitor wells would have to be located very close to a potential source of pollution. A thousand years might be required for such water to flow only a quarter of a mile. The key conclusion is that little effect on groundwater quality would be noticeable over the short term except in the immediate proximity of the stockpile. Flow rates in the alluvial aquifers (underflow) could be much greater. These are generally unknown, however, due to lack of data on aquifer characteristics and hydraulic gradients.

Land surface and vadose zone monitoring can provide information on travel times to the saturated zone and indicate when polluted water might be expected to reach the water table. The chemical aspects of pollutant transportation and attenuation are not considered further because of the relatively slow groundwater flow rates, which exert the controlling factor on pollutant mobility in the saturated zone.

Monitoring Needs--

Whether monitoring is justified to determine attenuation of stockpile pollutants in the saturated zone will depend entirely upon whether water will penetrate through the piles and the underlying materials to groundwater and, if it does, whether it would carry quantities of pollutants significantly exceeding those existing in the natural groundwater system. Both possibilities are unlikely. The stockpiled material may be highly permeable, but the underlying soil will probably be less so due to scraping and compaction. If the stockpile is placed on compacted mine spoils with a characteristically large, shale-derived component, penetration of water to the saturated zone will be greatly restricted. Furthermore, the only pollutants other than those that occur naturally or through oxidation would come from fertilizer applications, principally nitrates. Since fertilizer will only be used to assist development of a protective vegetative cover and not for agricultural production, application will be light.

Costs associated with Step 7 are those measuring or estimating the likelihood of pollutants infiltrating to the water table.

Recommendations--

No monitoring during Step 7 unless indicated by the results of previous steps.

PIT WATER

Step 3. Identify Potential Pollutants--Pit Water

Water entering coal mine pits can originate from a number of sources, each of which may contribute pollutants. Sources of this pit water include:

- Groundwater in the coal seam
- Groundwater percolating from nearby stream channels through alluvium beneath the flood plain
- Groundwater in the overburden
- Groundwater in the interburden and underburden
- Groundwater in spoils
- Direct precipitation
- Surface runoff into the pit
- Waste disposal, such as sewage treatment facility effluent.

A number of potential sources of pollutants may be in the pit water, such as:

- Coal
- Overburden, interburden, and underburden
- Explosives
- Spoils
- Solid waste
- Liquid waste
- Polluted streamflow
- Airborne pollutants and polluted precipitation
- Spills and leaks
- Natural sources, as a result of hydrogeologic modifications.

All of the potential pollutants from explosives--ammonium-nitrogen, nitrate-nitrogen, fuel oil, and trace organics--can be in the pit discharge. Most of the major inorganic chemical constituents and some trace elements can originate from groundwater percolating through the coal, overburden, and underlying beds. At Decker mine in Montana, high contents of sodium, bicarbonate, and sulfate, and occasional very high contents of nitrate, were found in pit discharge (Van Voast and Hedges, 1975). Calcium, magnesium, chloride, boron, and fluoride are additional potential pollutants. At Big Horn mine, high contents of iron, manganese, zinc, and copper were found in pit discharge. Cadmium, chromium, arsenic, lead, molybdenum, vanadium, uranium, thorium, radium, and selenium are additional potential pollutants. Organic materials from the coal and related beds are also potential pollutants.

Gasoline and oil can be introduced by heavy equipment working in the pit. Bacteriological pollutants can be introduced from domestic waste water, runoff, and solid wastes disposed of in or near the pits.

Monitoring Needs--

In areas where mining operations are above the groundwater table, any water accumulating in the pit may percolate downward and pollute the groundwater. Pit water then acts as a potential source of pollution. Conversely, when operations are situated at or below the groundwater table, pit waters serve as receiving waters for potential pollutants. Usually, this water must be disposed of by pumping to evaporation ponds or used in dust control operations.

Therefore, determination of the quality of water in the pit is needed. Secondarily, if water quality concerns are revealed in the pit waters, determination of the discrete origin of pollutants in the pit water is needed, which will likely entail additional monitoring beyond the pit.

Alternative Monitoring Approaches--

Nonsampling methods--A water budget approach using existing data and field measurements can be used to determine the amount of water in the pit.

Pit water discharge can be measured by installing a continuously recording flow meter in the discharge lines and keeping an account of the number of truckloads of water hauled for dust suppression. Precipitation falling on the water surface can be measured by installing a continuously recording rain gauge near the pit bottom. Evaporation can be measured indirectly by installing a floating evaporation pan. For both precipitation and evaporation determinations, the area of water surface in the pit must be known. This can be determined by periodic surveys. Aerial photographs can also be taken periodically to document the location of water bodies in the pit.

The volume of water entering the pit is more difficult to determine, because the water may come both from discrete sources, such as leakage at one location from a stream channel, and diffuse sources, such as seepage. For discrete sources, flumes or weirs can be installed near the point of entrance to the pit. Groundwater seepage into the pit from diffuse sources can be calculated if gradients and aquifer characteristics are known. The groundwater seepage can be characterized by a network of monitoring wells surrounding the pit. Aquifer tests and water level measurements would be necessary to determine the transmissivity and hydraulic gradient, respectively.

Items other than pit inflow and discharge can be measured, such as changes in water storage in the pit. A staff gauge used in conjunction with aerial photographs or water surface area surveys can be employed. Additionally, leakage from the pit can be estimated after other water budget items are determined.

Sampling methods--Water samples should be collected from pit water and discrete sources of water entering the pit. For water in the pit, samples should be taken at various depths since water quality may vary substantially. A depth-integrated sampler can be used from a small boat to sample various parts of the pit pond. A composite sampler can be used to continuously monitor the quality of water discharged from the pit. Grab samples can be collected from any discrete sources of inflow to the pit. Sediments beneath the pit water can also be collected for sampling.

Wells can be installed at the periphery of the pit to collect groundwater samples in the coal seam, overburden, underburden, and spoils. Changes in water quality along flow paths can be determined as groundwater approaches the pit. Generalized data from operating mines indicate that the effects of pit dewatering do not extend outward more than a few miles. Thus, any monitor wells should be placed within one-quarter mile or less from the pit. For groundwater percolating from streams, water samples can be collected from streamflow. Wells can also be installed to allow sample collection from the alluvium and to determine changes in water quality during percolation as groundwater approaches the pit. Both solid and liquid wastes that might affect the quality of pit water can be sampled for chemical analyses. In general, the latter type of monitoring would have the lowest priority, unless sampling of pit water suggests the necessity for this approach.

Water entering the upper part of a pit can traverse significant distances before joining the pit water body, in which case the water could pick up a number of pollutants from spills, native or disturbed materials, and other sources. Sampling this water at different locations along the traverse may prove helpful.

Monitor well construction should allow pump testing for optimal determination of aquifer transmissivity. Transmissivity values are a key input for calculating the rate of groundwater flow. A 4-inch-diameter casing is recommended to allow room for a submersible pump plus an electric sounder. Testing pumps are not permanently installed and, since PVC is the preferred casing material, it should be large enough to avoid damage during pump installation and removal. Also, for depths exceeding 100 feet or so, most casing strings are not perfectly straight, making extra space advisable. A 4-inch-diameter casing is generally adequate for pumping lifts of up to 300 feet, assuming the range of well yields normally encountered in coal regions. A 3-inch-thick gravel pack is generally recommended, but a 2-inch gravel pack would suffice for shallow wells in alluvium.

For monitor wells that are not to be pump tested, where water levels are to be measured and water quality samples collected, a 2-inch-diameter PVC casing can be used. Such a diameter would be feasible for monitoring groundwater quality in alluvium. In many cases, however, use of a somewhat larger-diameter casing is the least expensive procedure in the long term. Larger-diameter wells are easier to develop, easier to sample, and provide maximum use flexibility. For example, a water-level recorder can be more easily installed in a larger well.

An annular seal should be placed at the upper 10 to 20 feet of wells. Wells should be properly developed upon completion to remove drilling mud and other foreign materials. The top of the casing should extend several inches above the ground surface and a locking cap should be installed. Barriers should be constructed to prevent damage. Obviously, as the pit moves, some monitor wells will have to be abandoned and new ones drilled. Thus, it may be advisable to construct them with provisions for retrieval of the casing at a later date.

For deep wells, air rotary drilling is the usual method for overburden or coal above the water table. When saturated conditions are encountered, mud is added and drilling is by direct rotary, with a circulating drilling fluid. Bentonite is commonly used for drilling below the water table. Clinker is a special case and may be rather easily drilled above the water table. Circulation loss commonly occurs below the water table, however, even when drilling mud is used. Thus, bran, fiber, cement, or other materials are sometimes added. Bran, fiber, and other organic lost-circulation materials are themselves pollutants and their use in potable groundwater conditions should be restricted. The State of Montana forbids the use of these materials in drilling and plugging coal exploration holes. For alluvium, a common procedure is to drill an 8-inch-diameter hole with a flight auger and install a 4-inch-diameter PVC casing with a 2-inch-thick gravel pack. Annular well seals are usually bentonite.

Considerable attention should be given to well development. Monitor wells can be swabbed and bailed, air or water jetted, and finally pumped and surged. Use of a larger-diameter casing enhances proper well development. Upon completion of a well, a pump should be installed, pumping commenced, and water samples collected at frequent intervals during the first few hours of pumping. For alluvium, test durations of about 24 hours are usually adequate. The duration of tests in bedrock and clinker wells should depend upon the transmissivities and storativities of the aquifers, the types of tests, and the types of results desired. Where transmissivities are low and storativity is not being determined, single-well tests for 3 or 4 hours are generally sufficient. Where storativity is a desired result, longer tests with one or more observation wells are necessary. If directional permeability or aquifer boundaries are also to be evaluated, several observation wells and pumping for as long as a week may be required. Continuous water-level recorders installed at observation wells give the most dependable drawdown data. A step-drawdown test is advisable during the first part of the test to determine well losses. Water should be piped a sufficient distance from the pumped well to ensure that no recirculation occurs during the test.

A 1-inch-diameter sounding line should be installed for water-level measurements in the pumping well by electric sounder if a transducer is not utilized. Totalizing propeller-type flow meters or orifice plates should be used to measure the flow. Electrical conductivity, pH, and temperature of discharged water should be periodically measured during the pump test. About six water samples should be collected at different times during the test for chemical analysis of parameters to be monitored. Field determinations of pH, electrical conductivity, oxidation potential, and other parameters can be conducted simultaneously with pump testing to avoid duplication. From such data, the optimum duration of pumping before water sample collection can be determined. Sample collection procedures are given by Brown, Skougstad, and Fishman (1970) and Thatcher, Janzer, and Edwards (1977).

Pumping is the preferred method of sampling where well yields exceeding about 1/2 gpm can be obtained. Airlifting is commonly used in the Gillette, Wyoming area and may be the most feasible approach where wells yield less than 1/2 gpm. Consideration must be given, however, to changes in chemical composition that may be induced by the airlifting process.

Grab samples of pit water initially should be collected weekly. Before initiation of a routine sampling program, the variability in pit-water composition with depth and location should be determined. Results of this survey can be used to determine the number of samples required for each sampling round. The sampling frequency may be increased or decreased depending on results of the first several months of sampling. A composite sampling device may be necessary if grab samples prove inadequate. The date and time of sample collection should consider climatic conditions and operational procedures at the mine that might affect the quality of water sampled.

A quarterly sampling frequency is adequate for overburden and coal and semiannual sampling is adequate for deeper materials. In Wyoming, the Department of Environmental Quality specifies sampling monitor wells quarterly. The greatest constraint to more frequent sampling in many Western coal regions is adverse weather conditions.

The most complete analysis should be performed on the pit water. Samples of water should be examined for the major inorganic chemical constituents, including pH, electrical conductivity, and total dissolved solids (residue at 180°C). Selected samples should be examined for TDS (ignition at 600°F). Such determinations allow comparison of cation-anion sums, TDS versus electrical conductivity, and calculated TDS versus residue. Boron, phosphorus, and fluoride should be determined on all samples. Proper sample treatment and filtration techniques should be used (Brown, Skougstad, and Fishman, 1970). The various nitrogen forms should occasionally be determined. Trace elements that are recommended for frequent determinations include iron, manganese, cadmium, chromium, arsenic, lead, molybdenum, vanadium, cyanide, and selenium. An extensive list of trace elements should be determined early in the program and annually thereafter.

A gross indication of the organic chemical composition can be obtained by total organic carbon and dissolved organic carbon determinations. Oil, grease, gasoline, and selected pesticides should be determined early in the program and annually thereafter. For radiological composition, uranium and thorium contents and gross alpha activity, gross beta activity, and radium-226 activity should be determined. For bacteriological composition, total coliform and fecal coliform should be determined.

For solid materials accumulated at the bottom of the pit water, the nitrogen forms, trace elements, and total organic carbon should be determined on saturated extracts. Proper quality control procedures for laboratory analyses should be used.

Labor costs include inventorying and characterizing discrete and diffuse sources and field checking water quality and sample collection. Capital expenditures for sampling equipment are not required if these instruments have been obtained to sample sedimentation ponds. Grab samples of solid waste materials found in the pit water will not require additional equipment. Operating costs include those for analysis and transportation and storage of samples.

Recommendations--

A recommended general procedure is to perform the most complete analyses on water. Existing information on discrete and diffuse sources should be compiled and reviewed. Water entering the pit will not require complete analysis once it is characterized.

Grab samples of pit water initially should be collected weekly. Before initiation of a routine sampling program, the variability in pit-water composition with depth and location should be determined. Results of this survey can be used to determine the number of samples required for each sampling round. The sampling frequency may be increased or decreased depending on results of the first several months of sampling. A composite sampling device may be necessary if grab samples prove inadequate. The date and time of sample collection should consider climatic conditions and operational procedures at the mine that might affect the quality of water sampled.

Step 3. Identify Potential Pollutants--Impoundments

Potential sources of pollution within impoundments include pit discharge, sewage effluent, and surface runoff. Pit discharge may contribute a large amount of suspended solids, some or all of the major inorganic chemical constituents (calcium, magnesium, potassium, sodium, bicarbonate, carbonate, chloride, sulfate, sulfide, phosphate, etc.), and trace contaminants (including iron, manganese, zinc, copper, cadmium, chromium, arsenic, lead, molybdenum, vanadium, uranium, thorium, radium, and selenium). Among the potential pollutants in ammonium-nitrate/fuel oil (ANFO), used as an explosive for overburden removal, are nitric oxide, nitrogen dioxide, nitrous oxide, ammonia, hydrogen cyanide (0.10 pound of hydrogen cyanide is produced for each 120-ton charge of ANFO), fuel oil, and trace organics. Gasoline, diesel fuel, and oil may be introduced by heavy equipment working in the pit.

Pollutants introduced into impoundments from an onsite package plant include major inorganics and trace contaminants, organics (measured by total organic carbon [TOC], chemical oxygen demand [COD]), and microorganisms (Everett, 1979). Surface runoff into the pit includes both sediment and wastes deposited on the ground surface, such as oils, chemical spills, salts, etc., as well as salts, organics, and microorganisms flushed from the soil surface.

Monitoring Needs--

Monitoring needs include characterization of the sources of possible pollutants entering the impoundments, identification of potential pollutants entering the ponds, and determination of the chemical characteristics of the water in the ponds themselves.

Alternative Monitoring Approaches--

Nonsampling methods--One method of characterizing potential pollutants is to collect pollutant-specific information on monitoring activities relating to an impoundment. For example, water quality data may be requested, together with information on the status of a National Pollutant Discharge Elimination System permit for the basin. The NPDES permit also usually requires monitoring of flow, pH, total suspended solids (TSS), magnesium, and iron.

Alternatively, the quantities of water discharging into ponds from the main sources of potential pollution can be measured or otherwise characterized. For example, flow meters can be installed within pipelines used to transport pit water to ponds. Similarly, a Palmer-Bowlus flume or a weir can be placed in the line from a package plant. The watershed area above a pond can be characterized, and a rainfall-runoff relationship developed using techniques in the SCS National Engineering Handbook (Soil Conservation Service, 1972).

Another nonsampling method is to inventory sources contributing possible pollutants to the impoundments. For example, the mass of ANFO used in overburden removal and coal fracturing can be determined. Sources contributing to the package plant can be inventoried during a parallel program. The surface runoff area above ponds can be examined for surface stockpiles (e.g., topsoil, coal refuse, oil drums, etc.) containing potential pollutants. The sources can be located on a suitable base map.

Measurement of overflow from the ponds is required for an NPDES permit and these flow data may be used as part of the nonsampling program.

To obtain overflow measurements, appropriate weirs or flumes can be installed in a well-defined reach of the river into which ponds discharge or as close as possible to the ponds. An automatic stage recorder can be installed for continuous measurement.

Sampling methods--Water samples for characterizing pollutants within the impoundment and downstream runoff can be obtained from a number of locations. For example, pit water discharging into the impoundment can be sampled directly at the pipeline discharge point. Similarly, samples of package plant effluent and surface runoff into ponds can be obtained within the ponds and from the outfall to determine water quality transformations in transit. Finally, pond surface runoff can be sampled at a number of downstream locations.

Water sampling methods include grab sampling, automatic composite sampling, and automatic discrete sampling. Grab samples are obtained to determine instantaneous water quality. Composite samplers are used to obtain blended water samples over an appropriate time interval. Discrete samplers are used to extract water samples at timed intervals. The relative advantages and disadvantages of these techniques for wastewater sampling are reviewed by Harris and Keefer (1974).

Three alternative methods are possible for analyzing water samples. First, all samples may be submitted to a laboratory for complete analyses, including suspended sediment; major inorganics (calcium, magnesium, sodium, potassium, chlorine, HCO_3, SO_4, PO_4, SiO_2, NH_3-N, total-N, pH, and EC); trace constituents (iron, manganese, zinc, copper, chromium, arsenic, molybdenum, vanadium, thorium, rubidium, and selenium); hydrogen cyanide (possible byproduct of ANFO); organics (oils, grease); and microorganisms (total and fecal coliform). Recommended quality control measures (e.g., submitting duplicate samples to other EPA-audited laboratories) should be an integral part of this approach.

A second technique is to analyze completely the first few water samples collected during the program. Trace constituents found to be present in low concentrations can be excluded from further analyses. Similarly, cyanide, low-level organics, and microorganisms can be deleted from routine analyses. It is recommended, however, that each sample be completely analyzed for the major organics. Similarly, package plant effluent should always be checked for biochemical oxygen demand (BOD) and coliforms. Quality control measures should be implemented.

A third method is to analyze samples in the field for constituents such as total dissolved solids (TDS), pH, cloride, and nitrate. This approach requires the purchase of a portable field kit. When the results of such checks indicate a substantial change between tests, samples should be collected for laboratory analysis.

Selecting a sampling frequency to characterize the waterborne pollutants in a source such as a sedimentation pond is generally a trial-and-error process. One method is to sample frequently (e.g., every hour using a 24-hour discrete sampler) until time trends in the quality of the source are characterized. Subsequently, samples can be obtained by periodic grab sampling (e.g., weekly or monthly). An increase in sampling frequency may be warranted by unusual circumstances. For example, a spill of toxic substances on the watershed area draining into the ponds may justify an increase in sampling frequency.

Sampling frequency is also related to analytical costs. Thus, complete laboratory analyses of 24 samples collected during the 24-hour cycle of a discrete sampler may be prohibitively expensive and dictate 6- or 12-hour discrete samples or a single 24-hour composite sample.

The overall costs of Step 3 are high initially because of the need to completely analyze source samples. Later, the sampling frequency and requisite analyses can be reduced. Using field checks to determine sampling frequency is another cost-reducing technique.

- Labor costs include inventorying and characterizing sources, installing and operating water sampling equipment, field checking quality, and collecting and transporting samples.

- Capital costs include purchasing composite or discrete samplers and for equipment for field-checking quality. These items are capital items available for an overall monitoring program. Consequently, the proportionate charges against this source would be low.

- Initial operating costs for analyzing samples are high but will drop as the list of constituents to examine is narrowed and field checks are used to guide sampling.

Recommendations--

All of the above methods are important in a program to identify potential pollutants. However, source characterization, e.g., package plant discharge, will be included in parallel monitoring programs and is not considered here. Similarly, inflow-outflow rate relationships will be considered as a sampling item under Step 5, Evaluate Infiltration Potential. Consequently, the following preferred monitoring approach is recommended:

- Obtain available water quality data, including information on the National Pollutant Discharge Elimination System permit.

- Collect samples of pit water, runoff from disturbed areas, and sewage effluent discharging into the detention basin via composite or discrete samplers. These samples can be used to characterize incoming quality trends and to assist in determining water quality transformations during transit through the basin. In addition, time trends in certain quality parameters (e.g., biological oxygen demand, or BOD) may be warranted from results of parallel studies on the package plant. Subsequently, when trends are apparent, discrete grab samples can be collected.

- Grab-sample surface runoff flowing into the ponds at the inlet point.

- Grab-sample water at two or three locations within each pond and at two or three depths at each location to characterize quality transformations during transit of water through the ponds.

- Grab-sample pond discharge at the outfall point and at two or three downstream locations.

All water samples should be collected, preserved, and transported using recommended procedures (see Brown, Skougstad, and Fishman, 1970).

The following approach is recommended for analyses of water samples collected from sedimentation ponds:

- Completely analyze the first five water samples from each sampling location for all constituents using rigorous quality control measures.

- Analyze field samples for representative constituents (e.g., TDS, pH, nitrate, chloride). Collect samples for complete analysis if substantial changes in concentrations of these parameters occur during the nonsampling period.

- Analyze water samples collected on the basis of results under the second step only for those constituents found during the first step to be present in above-permissible concentrations. The major inorganics, however, should be completely analyzed and package plant effluent checked for BOD and microorganisms using rigorous quality control measures.

A preferred approach to sampling frequencies for sampling points related to sedimentation ponds includes:

- Sampling pit water and package plant effluent at their respective discharge points on a 6- and 12-hour basis, using discrete samplers, three or four times a week for 4 weeks, or until time trends in quality are characterized. Thereafter, obtain grab samples on a semimonthly basis, unless more frequent sampling is warranted (e.g., discharge of toxic chemicals from the pit).

- Grab-sampling surface runoff at the inlet point to the pit during one or two snowmelt runoff events and during one or two summer discharge events.

- Collecting water samples at two locations in both pit and sedimentation ponds at weekly intervals until quality trends are established. Thereafter, water can be sampled monthly.

- Collecting water samples at the outfall point from the detention basin at the same frequency and at the time that inflow discharges are sampled; that is, collect samples on a 6- or 12-hour basis, three or four times a week, until quality trends become apparent. Thereafter, discrete samples can be collected twice a month. Water samples should be obtained when available from the outflow channel. If flows are sustained, samples should be taken twice a month.

Step 5. Evaluate Infiltration Potential

Monitoring Needs--

The primary monitoring need is to determine the quantity of water seeping into the subsurface from the impoundment and outflow channel.

Alternative Monitoring Approaches--

Two methods are possible for estimating pond seepage: the water budget method and a seepage matrix. The water budget method requires determining inflow rates from all sources, outflow rates, evaporation-rainfall rates, and changes in storage. Inflow rates from the pit and package plant can be determined via weirs or flow meters. Runoff from the watershed draining into the ponds can be estimated from rainfall data and suitable rainfall-runoff relationships, such as developed by Craig and Rankl (1977). Outflow rates may also be determined via weirs or flow meters. The amount of water removed from the ponds for road spraying can be estimated from the capacity and number of truckloads utilized for dust suppression. Evaporation and rainfall rates can be determined by installing rain gauges and evaporation pans in the vicinity of the pond, by using meteorological data from an onsite station, or by using such data from a nearby station. The most cost-effective approach is to use data from an onsite station. Data from other areas may not be strictly applicable. Changes in storage can be determined by installing either staff gauges or an automatic stage recorder. The latter unit requires a stilling well and possibly a platform. Staff gauges offer the most cost-effective approach unless rapid changes in water levels are expected.

When all the above components of the water budget have been determined, seepage rates are calculated by differences.

Seepage meters provide point information on seepage. Such meters may be difficult to install and operate in sedimentation ponds. In addition, many observations are required in order to ensure meaningful results.

Infiltration in the outflow channel from pond overflow can be determined by using existing flumes, by installing flumes between measuring points, or by current metering of different outfall reaches.

Water budget determinations can be made on a continuous or intermittent basis. Continuous determinations require the installation of recording flow meters, automatic stage recorders, etc. Alternatively, the measurements required to compute a water balance can be obtained on a monthly or seasonal basis. In addition, measurements can be obtained before and after sedimentation removal. The surface mining reclamation and enforcement provisions require that sediment be removed from sedimentation ponds when the volume of sediment accumulates to 60 percent of the sediment storage required. After sediment removal, seepage rates will probably increase.

The principal costs for this effort include:

- Labor costs: conducting water balance studies, i.e., for installing weirs and flow meters; installing staff gauges on automatic stage records; collecting rainfall-evaporation data (or installing associated equipment); determining rainfall-runoff relationships for the contributing watershed; analysis and interpretation of data; and determining seepage in the outflow channel.

- Capital costs: weirs or flow meters, water stage recorders or staff gauges, and gauging station in the outflow channel.

- Operating funds for travel, chart paper, etc.

The foregoing capital items are general project items and costs would be apportioned to usage.

Recommendations--

The water budget approach is recommended. Although the initial cost of determining seepage rates via a water budget may be greater than by installing seepage meters, the results will be more accurate. In addition, capital items (e.g., weirs) may be general project items, reducing the cost apportioned to the impoundments. A cost-effective approach for monitoring infiltration through the outflow channel is to utilize existing gauging stations, where possible, supplemented with an additional station in an upstream or downstream location.

The preferred approach to conducting a water balance for impoundments is to obtain measurements on a monthly basis, until a seepage curve is obtained, and thereafter on a semiannual basis. Measurements should also be obtained before and after sediment removal.

Seepage rates in reaches of the outflow channel can be determined via an existing or project gauging station on a frequency dependent on pond overflow. If overflow is continuous, monthly measurements should be obtained. If overflow is periodic, measurements should also be periodic. Seepage rates should also be obtained during precipitation runoff.

Step 6. Evaluate Mobility in the Vadose Zone

Mobility and attenuation of potential pollutants in the vadose zone will depend entirely on the quantity of infiltration water, defined in Step 5, that enters the zone. Thus, this and subsequent monitoring steps will be implemented only when preceding studies indicate a need for further evaluation.

Monitoring Needs--

Data gaps exist in knowledge of the factors tending to attenuate pollutants within the vadose zone (i.e., dilution, filtration, sorption, chemical precipitation, buffering, oxidation-reduction, volatilization, and biological degradation and assimilation) and field data on transformations in waterborne pollutants during flow in the vadose zone.

Alternative Monitoring Approaches--

The potential attenuation of pollutants in the vadose zone can be depicted by constructing a table comprising attenuating factors (rows) versus specific pollutants (columns). Each location in the matrix specifies the relative potential of a factor (e.g., sorption) to attenuate a specific pollutant (e.g., zinc). Each position in the table may be filled in by subjective evaluation or on the basis of actual measurement. Subjective evaluation involves examining available data and estimating the effect on the mobility of a specific pollutant. Actual values from attenuating factors can be obtained from field measurements. For example, drill cuttings obtained during construction of wells can be analyzed to characterize cation exchange, pH, particle size, Eh, etc.

Obviously, completion of the matrix will be complicated by the interaction (synergistic or antagonistic) of attenuating factors. In addition, some factors may not be easily determined or estimated (e.g., volatilization). Consequently, the recommended approach is to use a mix of subjective estimates supplemented, when possible, with actual data.

Access wells through the vadose zone and a neutron moisture logger can be used to obtain water-content profiles. The vertical movement of water can be inferred by periodically logging in single wells. For example, water-content changes between daily logs show moisture accretion to, or drainage from, vertical segments of the vadose zone. In addition, the growth and dissipation of perched groundwater may be manifested on logs. The rate of lateral movement of perched groundwater can be inferred by monitoring water-content profiles in a transect of wells. Several construction methods are possible for installing access wells (e.g., rotary percussion, cable tool). However, the method providing the tightest fit should be selected. Access wells can be constructed of steel, PVC, or aluminum. PVC moderates the thermal neutrons used in moisture detection and results in poor resolution. Aluminum wells deteriorate under highly saline conditions.

Water movement in the vadose zone underlying impoundments can also be estimated by installing tensiometers and using methods described by Bouwer and Jackson (1974). Such units can be installed in several depths below the impoundment. Since tensiometers fail to function at water pressures less than -0.8 atmosphere, moisture blocks that function at lower pressures could be installed.

In order to characterize water movement beneath the outflow channel during pond overflow or natural discharge, access wells and/or tensiometers and moisture blocks can be installed at two or three locations.

To supplement the nonsampling program, field activities can be initiated to monitor the actual movement of pollutants in the vadose zone. Alternative methods include collecting drill or auger samples for laboratory analysis, installing suction cups, and installing sampling wells within perched groundwater bodies.

Collection of samples of vadose zone sediments entails using hand or power augers or core samplers. Depending on the physical composition of sediments underlying the ponds, hand-augered samples can be obtained to a depth of about 10 feet. If deeper samples are required, power equipment is needed. Samples may be collected (if possible) within the pond and in a transect away from the pond. Similarly, hand or power auger samples can be collected in the outflow channel and analyzed in the laboratory.

Suction-cup lysimeters can be installed throughout the vadose zone if the region consists of alluvium. Installations of cups in shale or standstone might cause postoperational difficulties. Suction cups can be installed as individual units, in depth-wise increments, or as multiple units in a common borehole. The cheapest approach is to install separate units to a depth of about 5 to 10 feet, say in 1-foot increments. Beyond 10 feet, borehole installation would be a more efficient alternative. For illustration of suction-cup lysimeter installations and operation procedures, see Fenn, Hanley, and DeGeare (1975).

Perched groundwater can be detected from neutron moisture logs. Perched groundwater regions may yield water in sufficient volume to permit sampling. In this case, PVC wells can be constructed to the perched regions and samples extracted by hand bailing or by pumping.

Water samples collected from suction-cup lysimeters can be analyzed completely or partially. Ideally, a complete analysis includes the major inorganics, trace constituents, and organics listed under Step 3, Identify Potential Pollutants. (The ceramic suction cups may filter out microorganisms.) Upon examination of the results of complete analysis, subsequent samples may be analyzed only for those trace constituents found present in greater-than-permissible concentrations. An initial complete analysis for major constituents is always recommended.

Solid samples can be used to obtain saturated extracts via techniques in Methods of Soil Analysis (Black, 1965). Saturated extracts can be employed to determine particle-size distribution, cation exchange capacity, EC, pH, and specific major and trace constituents, including boron, calcium, magnesium, potassium, chlorine, sodium, CO_2, HCO_3, and SO_4. Additional techniques are available for determining other trace constituents, such as copper, zinc, fluorine, selenium, cobalt, and molybdenum (Black, 1965). Organics can be determined using procedures described by Dunlap et al. (1977).

Water samples taken from PVC wells within perched layers can be analyzed. Alternatives include complete analysis of each sample; complete analysis of the first five to ten samples, until the water quality is characterized; partial analysis for those constituents found in excessive concentrations; and field checks.

Sampling frequency in suction-cup lysimeters depends on the water pressure within the surrounding porous matrix. If the matrix is very dry, water will enter the cups at a very slow rate. A week or more may be required to collect sufficient samples for analyses. In the extreme case, the cups become inoperable when water pressure is less than -0.8 atmosphere and samples may be available only once or twice a year. In contrast, if the porous system is very wet, samples may be extracted on a daily basis. The sampling frequency cannot be explicitly defined until field units are installed and operating. For a wet system, it may be desirable to collect samples on a more frequent basis (e.g., weekly) until quality trends are established. Later, samples can be obtained monthly.

Perched groundwater may be available only on a cyclic basis. Samples must then be obtained whenever possible. If perched groundwater is available continuously, samples can be obtained frequently (say, once a week) until quality trends are established. Later, samples can be collected monthly.

Costs associated with the recommended approach for monitoring in the vadose zone include:

- Labor costs: constructing an attenuation factor versus pollutant matrix and interpreting results; overseeing the installation of access wells and, subsequently, logging the wells; installing tensiometers and moisture blocks and collecting and interpreting results; obtaining and examining data from neutron moisture logs and tensiometer data to determine the flux of water (and pollutants) in the vadose zone; installing suction-cup lysimeters; collecting solid samples from the vadose zone; collecting water samples from the suction cups and PVC wells (if constructed); and conducting field checks on pH, EC, chloride, and nitrate.

- Capital costs: access wells; neutron moisture logger; tensiometers; suction-cup lysimeters; PVC wells; pH meter, EC bridge, and field kit for measuring chloride and nitrate (these items are general project items and associated costs for this step will be apportioned according to usage); and hand augers or power augers (again, these are project items).

- Operating costs: analytical costs for water samples (this cost is reduced when field checks are used to determine the need for laboratory analysis, and the number of requisite analyses is reduced throughout the program); analytical costs for analysis of auger samples; and transportation costs, sample bottle costs, etc.

Recommendations--

The preferred approach for estimating pollutant movement in the vadose zone comprises:

- Constructing a matrix of attenuation factors versus specific pollutants using available data when possible, supplemented with intuition.

- Installing three access wells laterally away from the impoundment into the uppermost aquifer.

- Installing two networks of shallow tensiometers and moisture blocks in each pond with individual units terminating in 1-foot increments to 5 feet beneath the base of the ponds.

- Installing a network of shallow access wells, tensiometers, and moisture blocks at three locations along the outflow channel.

- Installing suction-cup lysimeters in 1-foot increments to a depth of 10 feet below the base of the pond and in the outflow channel alluvium. Three sets of suction-cup lysimeters should be installed, one set within or immediately next to the pond, and the remaining sets at appropriate intervals along the outflow channel. If suction-cup samples show deep percolation of water, additional units should be installed at greater depths.

- Collecting solid samples for laboratory analysis of pollutants during installation of suction-cup lysimeters and PVC wells.

- Collecting additional auger samples of solids only as deemed necessary, or when suction cups are inoperable.

- Installing one PVC well within each perched groundwater body detected by neutron logging and sampling via a submersible pump.

A preferred approach for analyzing solid and water samples collected from the vadose zone comprises:

- Analyzing solid samples for major and trace constituents and organics. Particular attention should be paid to determining those pollutants found in excessive concentrations in the source during the program (Step 3, Identify Potential Pollutants).

- Analyzing the initial five to ten water samples from the suction-cup lysimeters completely for major trace constituents. Subsequent analyses should include all major constituents, but only those trace constituents found in excessive concentrations.

- Examining perched groundwater samples completely for major and trace constituents, organics, and microorganisms in the first five samples. Subsequently, only those trace constituents, organics, and microorganisms found in excessive concentrations should be determined. After the initial characterization, pH, EC, chloride, and nitrate concentrations can be field-checked. When substantial changes occur in these constituents, samples should be collected for partial analysis, as described above.

A preferred approach to sampling frequency is:

- Sampling suction cups whenever possible during very dry conditions. For wet conditions, sampling weekly until quality trends are established; thereafter, sampling monthly.

- Obtaining and analyzing solid samples only during installation of suction cups and PVC wells.

- Sampling PVC wells at a frequency depending upon availability of free, perched groundwater.

Step 7. Evaluate Attenuation of Pollutants in the Saturated Zone

As pointed out by Todd et al. (1976), the principal processes involved in attenuating pollutants in the saturated zone include decay, physical-chemical reactions, and dilution. For pollutants in a source, such as a sedimendation pond, physical-chemical processes and dilution may be of prime significance. Included in the physical-chemical processes are adsorption, precipitation, volatilization, oxidation-reduction reactions, etc. Dilution is through hydrodynamic dispersion resulting from such effects as convection diffusion and flow tortuosity.

Dispersion (or dispersivity) within an aquifer is difficult to determine without careful, extensive field experimentation. A qualitative notion of dilution resulting from dispersion may be obtained from knowledge of the following (see Todd et al., 1976): volume of wastewater reaching the water table, the waste loading, areal-head distribution, transmissivity values, vertical hydraulic-head gradients and permeabilities, groundwater quality, quantity and quality of recharge from other sources, and pumpage volumes and patterns.

Monitoring Needs--

Information gaps currently exist in predicting the effects of dilution and physical-chemical reactions on pollutant attenuation within aquifers underlying impoundments.

Alternative Monitoring Approaches--

The relative effect of various physical-chemical mechanisms for attenuating pollutants within the saturated zone can be estimated by constructing a matrix similar to that for the vadose zone, consisting of attenuating mechanisms (rows) versus pollutants (columns). Attenuating mechanisms consist of physical-chemical factors: sorption, precipitation, volatilization, oxidation-reduction (Eh), decay, and dilution. The completed table will show, in a mixed qualitative-quantitative sense, the pollutants that should be monitored.

Knowledge of geochemical processes naturally active in the system can be valuable in predicting the transport and attenuation of pollutants. For example, Thompson and Van Voast (1981) describe processes of salt dissolution, cation exchange, and sulfate reduction as being highly active in the flow system southwest of Decker, Montana. Pollutants entering that system are subject to these processes and attenuated or transported accordingly.

Completion of the matrix for the physical-chemical items requires specific information on exchange capacity of aquifer materials, on the Eh and pH of groundwater, and on the specific pollutants entering the zone of saturation. Many of the physical-chemical parameters can be quantified from analyses of drill cuttings obtained during well construction and from field analyses of Eh and pH. Identification of pollutants must await the results of mobility studies in the vadose zone.

Estimating the effect of dilution on pollutant attenuation requires data on items listed previously, i.e., volume of wastewater reaching the water table, the waste loading, areal-head distribution, aquifer transmissivity, vertical hydraulic-head gradients and permeabilities, groundwater quality, quantity and quality of recharge from other sources, and pumpage volume and patterns. The volume of pond water reaching the water table may be estimated from data on seepage rates (see Step 5, Evaluate Infiltration Potential), assuming that steady-state seepage has been reached and that the water content of vadose sediments equals or exceeds field capacity. Water content data from access wells installed earlier is useful in verifying these assumptions. Similarly, neutron moisture logging data in a transect of access wells may indicate the lateral spread of pond water within the vadose zone and, consequently, the waste loading rate. Installation of additional access wells may be necessary to obtain adequate resolution. Areal head distributions in the aquifer can be obtained via a set of wells. Similarly, piezometer clusters may provide data on vertical hydraulic gradients and possibly on vertical hydraulic conductivity. Aquifer transmissivity values may also be obtained as a result of earlier pumping tests on wells. Groundwater quality can be quantified as a result of activities during Steps 5 through 7. The quantity and quality of recharge from other sources may be the most difficult items to identify. Use of available data, e.g., on seepage rates in the outflow channel, may be possible. Similarly, information on pumping rates in existing wells can be solicited from mine managers.

In lieu of constructing an attenuation matrix, an alternative method is to initiate tracer studies to estimate the spread and attenuation of pollutants. For example, a conservative tracer, such as chloride, could be injected in one of the upstream wells installed earlier and water samples extracted periodically from downstream wells. In light of possible low transmissivity values in shallow aquifers, however, the time to obtain a tracer breakthrough in downstream wells could be excessive.

Groundwater samples can be obtained for analysis and ensuing data examined to characterize pollutant attenuation. A network of wells can be used in such a program. In actuality, a special sampling program should not be required, because of available samples from these wells.

Obtaining vertical samples within the water-bearing strata being examined is imperative. The rationale for this necessity is stated by Mooji and Rovers (1976):

> In the past it was frequently assumed that the monitoring of the upper few feet of an aquifer was adequate as it was assumed that the contaminants migrated vertically to the water table followed by lateral migration in the upper zone of the aquifer. In fact, recent research studies show that the contaminants can migrate to the bottom of the aquifer prior to extensive lateral migration taking place .... Therefore the preferred method is to install piezometers at varying depths throughout the thickness of the aquifer.

In lieu of, or to supplement, piezometer clusters, alternative methods for obtaining depthwise samples from a given water-bearing formation include multilevel samplers and groundwater profile samplers. Details of a multilevel sampling well designed by Pickens et al. (1977) are illustrated in Figure 3-1. This well consists of PVC or steel well casing, openings at desired incremental depths, screened coverings on openings, and polypropylene tubing sealed onto the openings, extending to the surface. According to Pickens et al. (1977), this unit may be used to depths of 100 to 130 feet. Its advantages are that depthwise sampling is facilitated and overall construction costs may be lower than for piezometers. A suitable pumping unit may be the type used to purge tensiometer units (available from Soil Moisture Equipment Company, Santa Barbara, California).

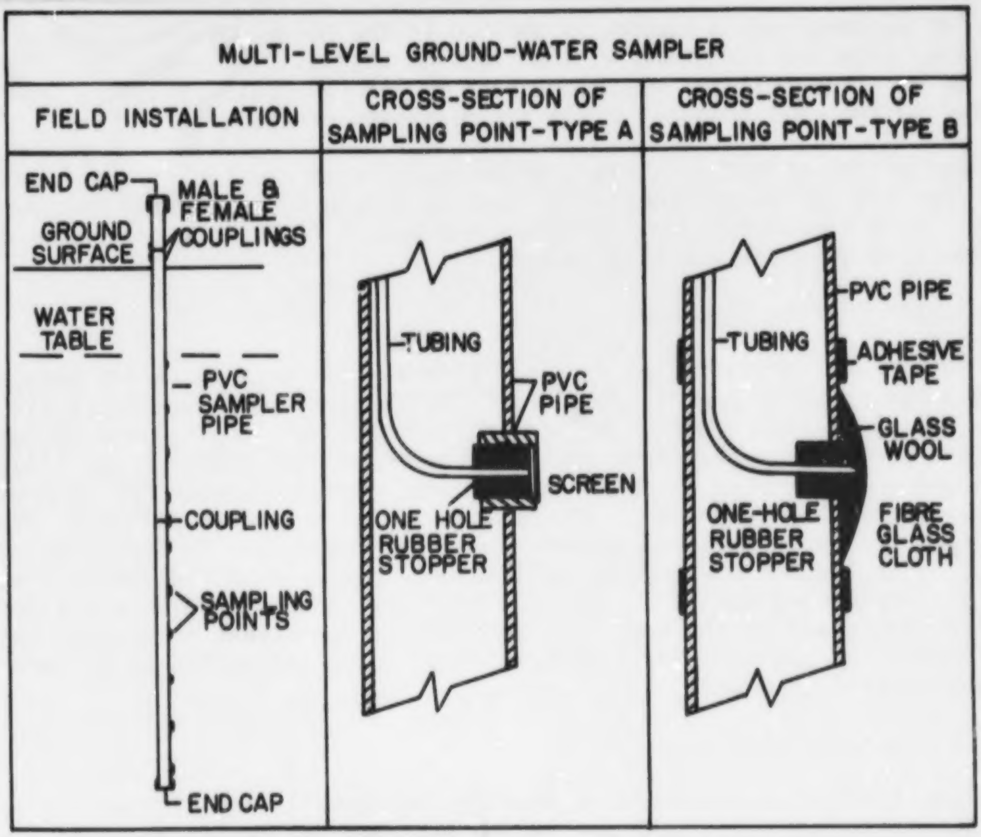
MULTI-LEVEL GROUND-WATER SAMPLER
FIELD INSTALLATION
CROSS-SECTION OF SAMPLING POINT-TYPE A
CROSS-SECTION OF SAMPLING POINT-TYPE B
END CAP
MALE & FEMALE COUPLINGS
GROUND SURFACE
WATER TABLE
PVC SAMPLER PIPE
COUPLING
SAMPLING POINTS
END CAP
TUBING
PVC PIPE
SCREEN
ONE HOLE RUBBER STOPPER
TUBING
PVC PIPE
ADHESIVE TAPE
GLASS WOOL
ONE-HOLE RUBBER STOPPER
FIBRE GLASS CLOTH

Figure 3-1. Multilevel groundwater sampler (after Pickens et al., 1977).

An alternative depthwise sampler was designed by Hansen and Harris (1974). The unit, called a "groundwater profile sampler," is shown in Figure 3-2. Basically, the sampler consists of a 1.25-inch-diameter well point, of optional length, with isolated chambers containing fiberglass probes. The individual chambers are filled with sand and separated by caulking compound. Small-diameter tubing provides surface access to the probes. The positioning of probes is optional, depending on aquifer materials, desired sampling frequency, etc. In operation, a vacuum is applied to the sampling flasks. Hansen and Harris (1974) recommend simultaneous extraction of all samples at the same rate to minimize variation in aquifer thickness sampled by the individual probes. Water tables as deep as 30 feet may be sampled by the unit.

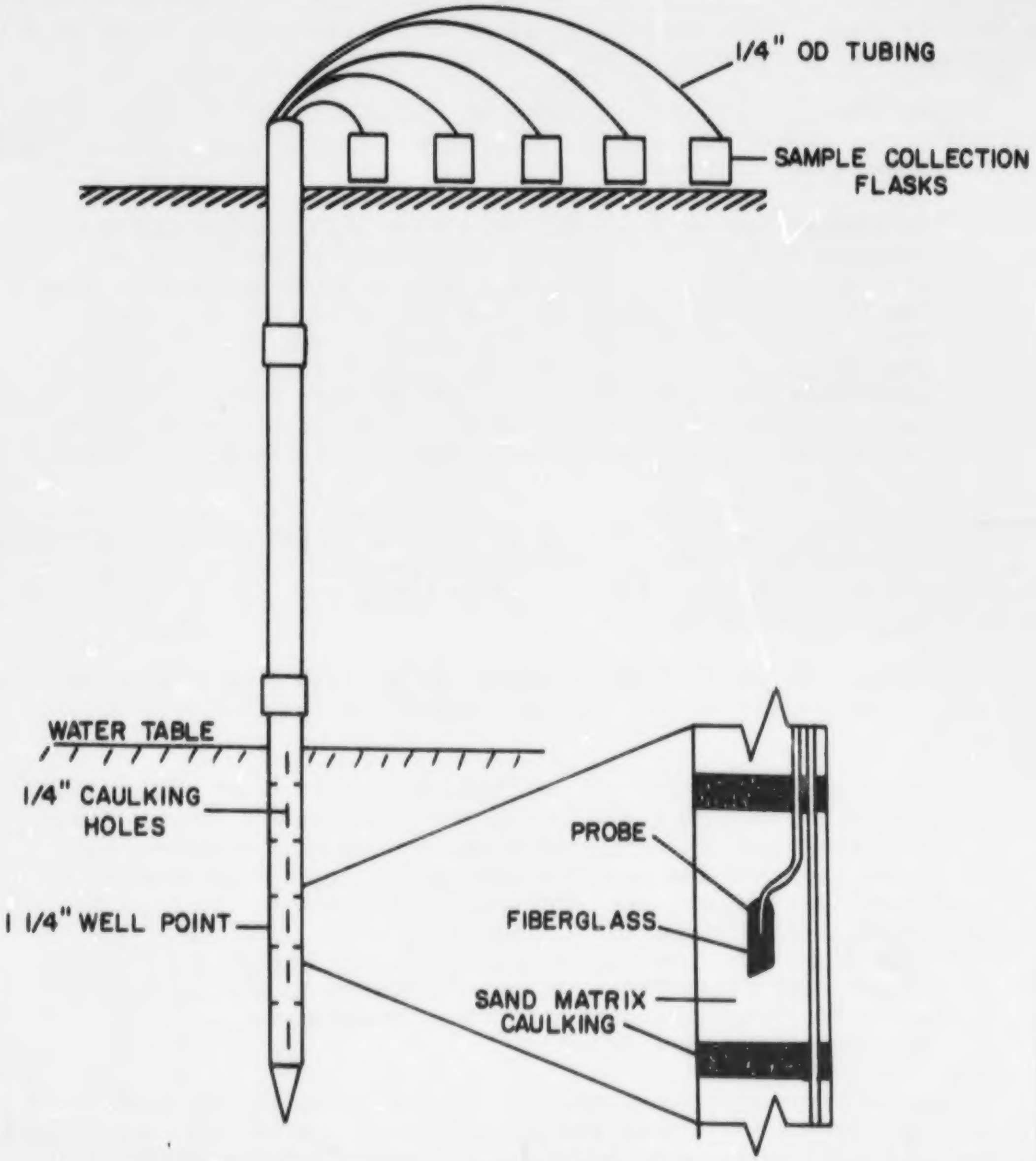
1/4" OD TUBING
SAMPLE COLLECTION FLASKS
WATER TABLE
1/4" CAULKING HOLES
1 1/4" WELL POINT
PROBE
FIBERGLASS
SAND MATRIX
CAULKING

Figure 3-2. Groundwater profile sampler (after Hansen and Harris, 1974).

The costs for the proposed approach consist of:

- Labor costs for obtaining data to prepare and interpret the attenuation mechanisms versus pollutant matrix
- Capital costs for additional wells.

Recommendations--

A preferred monitoring approach includes:

- Constructing an attenuating mechanism versus pollutant matrix, using available data whenever possible.
- Conducting tracer studies if two monitor wells are deemed to be sufficiently close that short-time studies are possible.
- Using monitor wells installed during previous steps and installing additional piezometer clusters as necessary to obtain samples for characterizing the vertical distribution of quality (the other methods, multilevel samplers or groundwater profile samplers, are not recommended unless the water table is very shallow).

SECTION 4

MONITORING RECOMMENDATIONS FOR RECLAIMED MINE SOURCES OF POLLUTION

Steps 3, 5, 6, and 7 of the groundwater quality monitoring methodology have been developed for reclaimed mine sources of pollution as identified in Table 1-2. The reclaimed surface coal mine sources of potential pollution include spoils and reclamation aids. Step 8 is a mine-specific application of the methodology and is presented in Everett (1979).

SPOILS

Spoils are largely composed of overburden and interburden materials that have been removed from the zone between coal seams and between the coal and soil removed before stripping the coal. Minor amounts of material from the coal and soil zones, as well as artificial wastes, may also be present. The spoil materials are generally replaced in the pit area from which they were removed. They are physically disturbed, however, as compared to the original generally stratified sedimentary deposits of the premining overburden.

This physical disturbance of the geologic strata results in a corresponding disturbance of the premining chemical equilibrium between the earth material and its surrounding environment. Various leaching processes acting over geologic time remove most of the readily soluble constituents that are exposed or accessible to leaching in the undisturbed overburden. Thus, most of the readily soluble materials have been removed from the strata that are permeable to water, while a considerable quantity of soluble constituents may still remain in the relatively impermeable strata, such as finer-grained clastic rocks including clay, silt, and shale.

Dislodging and mixing of the natural geologic stratigraphy, however, exposes new lithologic surfaces and mineral constituents that may be susceptible to chemical-physical interaction with the water, air, biological, and mineral components of the environment. Fracturing of the rock structure may also increase permeability to water and, in some instances, to air, thereby facilitating these interactions.

Through dissolution, ion exchange, and other chemical interactions, certain minerals are released and may then be transported in solution to downgradient locations above or below the water table. From there, they may continue along flow paths to points of surface discharge. In contrast, some of the minerals that are released from their parent materials at depths of several feet or less may be subject to upward capillary movement into soil zones.

Potential pollutants may be generally defined as being those constituents of spoil materials that are likely to go into water solution under local geological, hydrological, climatic, or other physical-chemical processes and conditions and that might adversely affect usefulness of the water resources by man, animals, or plants. Water pollution is normally thought of as being a condition that results when undesirable materials are added to water, but can be even more broadly defined to include the removal of certain desirable chemical constituents (e.g., as by ion exchange) or by changing physical characteristics (e.g., temperature and color). The potential pollutants may differ with geographic location and stratigraphic depth of the mining and reclamation activity. They may also change with time after emplacement of the spoils in response to changes in the physical-chemical processes and the availability of certain pollutants.

Although the potential pollutants tend to be site-specific, generalized information on pollutant conditions and processes observed in other regions, at other coal operations, and in laboratory research can be useful in predicting and identifying local potential pollutants.

Palmer and Cherry (1979) have evaluated the chemical composition of groundwater and undisturbed overburden in the Fort Union Coal Region of Western North Dakota, Montana, Wyoming, and Saskatchewan and have concluded that the chemical evolution of groundwater is governed by the processes involving oxidation of organic material in the soil zone, dissolution of calcite and dolomite, oxidation of pyrite, precipitation of gypsum, dissolution of gypsum, cation exchange, and sulfate reduction.

In the western United States, the primary groundwater contamination problem associated with surface coal mining is the elevation of total dissolved solids (TDS) levels in spoil groundwaters. The soluble salts observed to be the principal constituents responsible for the elevated TDS levels are the salts of sodium, calcium, magnesium, and sulfate. Column leach experiments conducted by several researchers indicate that the salinity of spoil groundwaters will decrease over time as successive volumes of water leach the spoils mass. The time frames necessary for TDS levels to approach baseline levels are highly dependent upon the degree of TDS contamination and site-specific conditions responsible for groundwater flow rates that will leach the spoils. For example, leaching experiments in conjunction with groundwater calculations at the Yampa River Coal Company's Energy #2 mine in northwest Colorado indicated that the return to baseline TDS levels would take approximately 75 years (Mining and Reclamation Plan, Energy #1, #2, and Eckman Park mines). At nearby Edna mine (Pittsburg and Midway Coal Company), similar testing and calculations estimated that approximately 700 years of leaching are necessary at that site (Edna Mining and Reclamation Plan) in order for water quality (TDS) to return to levels observed in undisturbed areas. Spoil leaching tests do not account for the time element and associated weathering rates that can cause an unknown amount of groundwater degradation.

The processes involved in elevating TDS levels in spoil groundwaters is a topic of debate. The principal processes responsible for spoil-water degradation reported by Palmer and Cherry (1979) are the oxidation of pyrite and associated dissolution of carbonate minerals. Recent work conducted by Koob (personal communication, 1982) at North Dakota State University, however, indicates that insufficient amounts of sulfide (or organic sulfur) are present in the spoils to be responsible for the manyfold increase in sulfates seen in spoil groundwaters. He theorizes that in undisturbed overburden, an equilibrium is reached between the oxidation of sulfides (and organic sulfur) near the land surface with a slow migration of the byproducts of this process (salts, primarily sulfates) to groundwaters. The large quantities of sulfates already present in the overburden are made available for dissolution in spoil groundwaters after the mining process relocates these materials in the saturated zone or in locations where the materials can be leached.

Van Voast, Hedges, and McDermott (1978) concluded from their leaching experiments that the rapidity of dissolution strongly indicates that the salts are readily available in soluble form in the overburden and that the reactions creating them had occurred long before the overburden was disturbed. Premining overburden sampling is essential to identify overburden zones that may contribute significantly to levels of TDS and sulfates in spoil groundwaters.

Dollhopf et al. (1978) mention that during an extensive program to delineate overburden inimical zones at Rosebud mine (Area B) in Montana, the materials high in soluble salts (measured by electrical conductivity) are usually found within a few meters of the surface. Harrington (Montana Department of State Lands, personal communication, 1982) has also noticed in his review of overburden data from several mines in Montana that materials with high salinity are generally quite shallow (less than 15 meters). The normal dragline strip mining operation would generally place the near surface overburden at the base of the pit resulting from the previous mine cut. This mining practice places the more saline materials in the resaturated zone and may be responsible for the most significant groundwater degradation observed in spoil groundwaters (i.e., elevated TDS, particularly sulfates). Any program designed to characterize the geochemistry of overburden materials should acknowledge the importance of measurements of electrical conductivity (on saturated paste extracts). When saline overburden materials are observed, care should be taken to determine the extent of the saline zone and a decision made whether or not to selectively place the materials out of the resaturated zone and out of zones where percolation of moisture through the saline material is likely. When sulfates are the primary component of the saline zone, particular consideration should be given to what the addition of sulfates to the postmining groundwaters will mean to potential water users. The levels of sulfates in groundwaters may be the most limiting parameter to be affected by surface coal mining because concentrations as low as 500 mg/l can affect livestock (McKee and Wolf, 1963).

Dollholf et al. (1981) mention that during a research project involving selective burial of saline materials conducted at Rosebud mine in Montana, detailed measurements of deep percolation revealed topography. In semiarid areas, then, the logical location for placement of spoils high in soluble constituents would be beneath surface landforms that would enhance runoff and minimize infiltration.

Step 3. Identify Potential Pollutants

In identifying potential pollutants at a proposed mine site, it is desirable to have an understanding of the local geological, hydrological, chemical, physical, biological, and other environmental conditions and processes that may determine whether certain mineral species are present and might reasonably become groundwater contaminants.

In many parts of the West, the more soluble salts contribute most to the initial mineralization of groundwater. These include salts of sodium, magnesium, calcium, and sulfate. These highly soluble pollution sources tend to be depleted with time, but not necessarily at the same rates. Typically, as leaching continues, the salinity of the water decreases as the more soluble sodium and magnesium cation source materials are depleted. Concurrently, the relative concentration of the calcium cation increases in the leachate. For example, Yampa Rivers Coal Company's Mining and Reclamation Plan for the Energy #1, #2, and Eckman Park mines in northwest Colorado presents the results of leaching tests indicating spoil-water quality levels (in terms of TDS) will be elevated above the baseline water quality levels. The leaching study further indicates that the readily soluble constituents are removed and the TDS levels gradually decrease over time. The volumes of water relative to spoil mass used in the leaching tests when compared with the field hydrologic conditions indicate spoil water qualities could return to baseline levels in less than 100 years. Similar leaching tests and associated calculations conducted for the Pittsburg and Midway Edna mine indicate that baseline water quality would be approached 700 years following mining.

In all studies of this type, the effect of time as it may relate to weathering and release of additional soluble constituents cannot be assessed. Researchers agree, however, that an initial slug of soluble constituents introduced to the spoil groundwater system upon resaturation will decrease over time.

Over a longer term, the presence of sulfide mineral sources (e.g., pyrite) in the spoils may exert a relatively strong influence on groundwater quality. Abundant pyrite in the presence of oxygen will oxidize to produce large amounts of sulfate, resulting in acid water unless excess carbonate minerals are present. Even though the pH may be kept neutral or slightly basic by the dissolution of carbonates, salinity can increase to higher levels as the pyrite oxidizes and the carbonates dissolve (Moran et al., 1979). A mitigating factor in semiarid western mine settings is a general paucity of infiltration from precipitation. Most hydrologists who have studied these settings agree that significant recharge occurs only in specific locales where precipitation accumulates or is retained long enough to penetrate beneath the root zone.

Identification of potential pollutants should be considered as a data collection process that can effectively begin before the mining period and extend through the mining and postmining phases.

In the West, spoil waters are rarely acidic. Commonly, sufficient carbonate minerals and alkaline salts are available to neutralize any acid production resulting from the oxidation of sulfides (pyrites) and organic sulfur. However, the oxidation of pyrite and organic sulfur causes an elevated level in TDS caused by the dissolution of alkaline materials such as the carbonate minerals. The result can be elevated levels of TDS, particularly sulfate, that could render groundwater unsuitable for livestock use.

The opportunity exists during the mining process to minimize the oxidation of pyrites and production of sulfates by burying localized pyritic zones in the postmining saturated zone. Pionke and Rogowski (1979) state that water has an oxygen diffusion coefficient four magnitudes less than for sulfides in air and, therefore, limits the oxidation reaction rate.

Another method to limit the groundwater degradation from sulfate production associated with oxidation of pyrites is to bury the pyritic material where it will not be transported into the groundwater. In areas of little, if any, deep percolation, burial of the pyritic zone above the saturated zone would not slow the oxidation of pyrites but would effectively limit groundwater degradation by isolating the sulfates that are produced. Dollhopf et al. (1981) found at Rosebud mine in Montana that very little deep percolation occurred at a selective burial monitoring site that was overlain by a hillslope landform. Dollhopf et al. suggest that selective burial of spoils high in soluble constituents should be done above the resaturated zone under sloping landforms that will minimize percolation of moisture.

Concentrations of pyrites are not uncommon in carbonaceous materials such as rider coal seams or carbonaceous shales overlying coal seams, as well as in other isolated strata (personal communication, D. Fransway, 1982). Table 4-1 is an example of overburden data taken from a mine near Gillette, Wyoming (personal communication, D. Fransway, 1982) showing a zone high in pyrites and/or organic sulfur as evidenced by the high total concentrations. Selective burial of zones such as in Table 4-1 showing high pyrite levels would help minimize degradation of spoil groundwaters.

Research is being conducted at Montana State University on an appropriate calculation for assessing the acid-neutralization potential of spoil materials. Dollhopf (personal communication, 1982) has found that sulfur detected by total sulfur analyses has been as much as 70 percent organic sulfur. In contrast, total sulfur analyses in the eastern United States generally show less than 1 percent organic sulfur. The significance of this finding is that the potential activity associated with the organic form of sulfur has not been accounted for in acid-neutralization potential calculations in the West. According to Dollhopf, organic sulfur when oxidized produces approximately one-third less acid than the sulfide forms of sulfur. Therefore, calculations regarding the acid-neutralization potential of spoils such as that described by Smith et al. (1974) should account for the potential acidity associated with the organic and sulfide forms of sulfur in the spoils.

A disparity of opinions exists on the appropriate density of overburden samples. Overburden sampling in Montana, Wyoming, and North Dakota is required on a grid spacing ranging from 600 to 1,500 meters. These states have the most demanding overburden characterization requirements of the western states. A recommendation was made by the Department of the Interior, Bureau

TABLE 4-1. OVERBURDEN ANALYSES FROM A SURFACE COAL MINE NEAR GILLETTE, WYOMING, SHOWING NET POTENTIAL ACIDITY ASSOCIATED WITH ISOLATED STRATA (D. Fransway, Wyoming Department of Environmental Quality)

				Tons $CaCO_3$/1,000 Tons Material		
Sample Number	Depth (feet)	Total Sulfur (percent)	SO_4-S (percent)	Maximum Required	Present Neutralization Potential	Amount Needed for Neutralization
Hole #200	0-10	0.37	0.11	8.13	9.56	17.69[a]
	10-13	0.28	0.02	8.13	-12.00	20.13[a]
	13-20	0.20	0.02	5.63	-4.00	9.63[a]
	20-30	0.18	0.06	3.75	-3.50	7.25[a]
	30-35	0.70	0.21	15.31	-5.50	20.81[a]
	40-45	0.66	0.08	18.13	3.75	14.38[a]
	45-55	0.62	0.06	17.50	43.13	-25.63
	55-56	1.00	0.12	27.50	22.25	5.25[a]
	65-73	0.30	0.02	8.75	2.75	6.00[a]
	73-80	0.54	0.10	13.75	14.25	-0.50
	87-95	0.60	0.05	17.19	5.13	12.06[a]
Hole #203	0-5	0.76	0.01	23.44	-46.25	69.69[a]
	5-10	0.23	0.01	6.88	-7.88	14.76[a]
	10-20	0.10	0.01	2.81	30.25	-27.44
	20-29	0.04	0.01	0.94	3.75	-2.81
	20-35	0.05	0.01	1.25	47.00	-45.75
	35-41	0.05	0.01	1.25	4.50	-3.25
	41-49	0.12	0.01	3.44	29.38	-25.94
	51-59	0.10	0.01	2.81	5.75	-2.94

Note:

[a] Zones showing net acidity requiring $CaCo_3$ for neutralization calculated according to methods in Smith et al., 1974. Calculations used do not account for any difference in potential acidity associated with the forms of sulfur (sulfides versus organic sulfur).

of Land Management (1977), "For a limited amount of sampling and analysis of overburden in the Fort Union Region ... the rock material is homogeneous and ... the concentrations of potentially harmful elements are not high. We feel that it is not justifiable to spend large amounts of money for a slight increase in the confidence that minor zones of high concentration have not escaped detection." In contrast, Dollhopf et al. (1981) conducted a research project using high-density overburden sampling to delineate chemical migration inhibitory zones.

The salient point is that groundwater degradation should be minimized whenever possible. The site-specific harm that may come from introducing a localized chemical migration inhibitory zone into the groundwater versus the economic cost of selective burial of such material is a regulatory matter that cannot be resolved in this document.

Dollhopf et al. (1981) evaluate the accuracy of varying drilling intensities while attempting to delineate chemical migration inhibitory overburden zones at the Rosebud mine in Montana with regard to elevated soluble salts, nickel, and clay contents:

> Of course, there is one inescapable conclusion. That is, as drilling intensity increases, our ability to accurately define overburden inhibitory zones increases [Figure 4-1]. Ideally, in biological-environmental systems, we would like to make correct evaluations at least nine times out of ten (i.e., with 90% accuracy). If we apply this criterion to the regression equations presented in Figure 4-1 to clay and soluble salt prediction, then we see the required drilling intensity would approach a 43 m grid. Our ability to characterize unsuitable overburden with drill holes 600 to 1500 m apart as recommended by States has an accuracy of only 45 to 60%. This means that it is probable that a typical premine overburden assessment program missed detecting half of the unsuitable materials in the project area. Since our ability to predict inhibitory (or noninhibitory) status of overburden between two boreholes approaches a 50% accuracy, our ability to predict the presence of absence of inhibitory material between such boreholes is very limited. Therefore, when reconnaissance overburden sampling is performed, it may very likely be a false interpretation to assume noninhibitory overburden will be present between two adjacent boreholes which did not intercept inhibitory material. Considering that western states sample overburden in a 600 to 1500 m grid fashion, it is likely that incorrect interpretations are being made resulting in inhibitory materials being unknowingly deposited either in the future aquifer zone or root zone.

Dollhopf et al. acknowledge that intensive sampling could become prohibitively expensive. They suggest a two-phase approach that begins with a wide grid spacing (i.e., 600 meters). Following the initial overburden analyses, only the parameters that occurred above or near inhibitory levels would be considered in the second phase of sampling. The second intensive drilling and

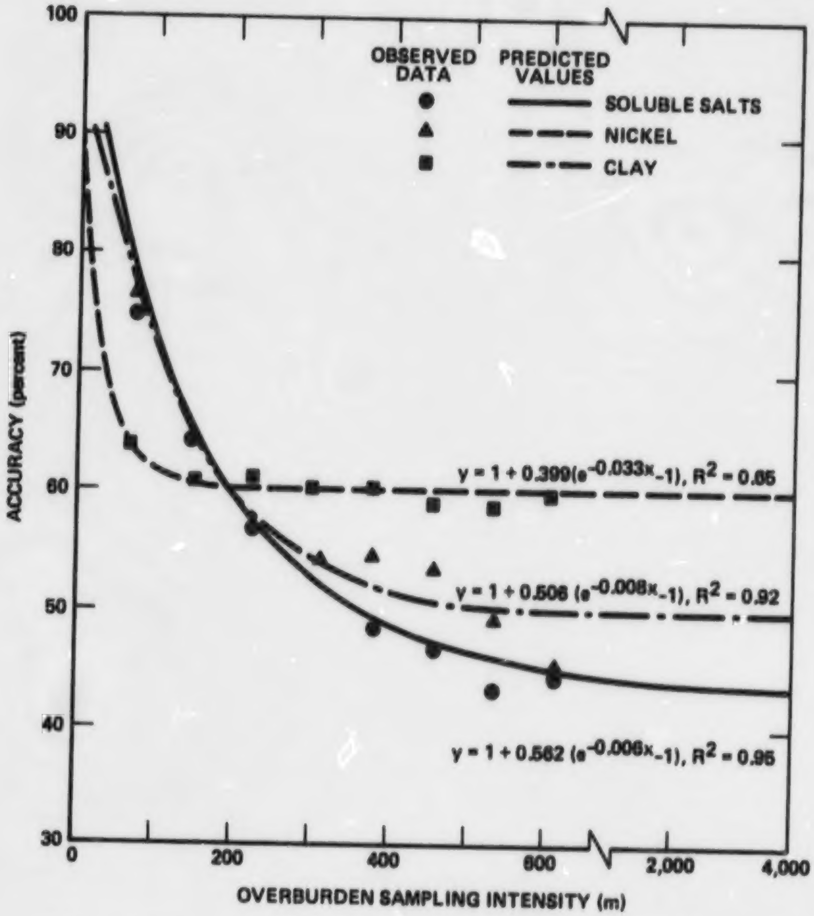

Figure 4-1. Accuracy in characterizing unsuitable overburden zones as a function of drilling intensity for soluble salts, nickel, and clay at Rosebud mine near Colstrip (Area B), Montana (Dollhopf et al., 1981).

sampling program would be designed to attain a characterization accuracy of 80 to 90 percent of a chemical migration inhibitory zone. To attain that accuracy, a 60-meter drilling would be necessary. Another way to save drilling costs and yet maintain the characterization accuracy would be to couple the overburden sampling with the drilling of the highwall for blasting. This suggestion has problems because frequently insufficient time is available between the drilling, blasting, and removal of the overburden to allow the mine operator to react to the results of the geochemical analyses. Drilling and sampling of the mine highwall, however, may be best utilized to guide subsequent drilling (back from the highwall) and delineation of potential inhibitory zones.

The recommended drilling intensities should be considered site-specific and, while they provide insight to acceptable drilling intensities for other mine sites, the recommendation should not be considered absolute.

In many instances, it may be relatively simple to identify or predict potential pollutants during the premining stage while they are confined to their natural positions within the geologic strata. At this time, correlation of data from test holes in the proposed mining area may be sufficient to show the three-dimensional distribution of rock types, thickness, and elevation throughout the proposed mining zone. These stratigraphic data, in combination with information on potential pollutants in each respective stratum acquired by sampling during drilling and subsequent field or laboratory analyses, provide a corresponding three-dimensional picture of potential pollutant distribution.

In the postreclamation period, detecting, identifying, and locating potential pollutants after they are highly scattered at possibly unknown locations and depths in the spoil mass may be considerably more difficult and expensive than it would have been at earlier stages. It would be preferable to:

1. Identify during the planning/exploration period the types of potential pollutants in the undisturbed overburden and their stratigraphic position, with particular attention to those types that may be especially toxic, acid forming, or otherwise troublesome (e.g., zones high in pyrite). Reliable extrapolation of information for great distances from a test hole drilled in undisturbed stratified overburden may be possible, whereas a later sample from the spoils consisting of the same but highly mixed materials may not reflect conditions existing more than a few feet from the hole.

2. Observe and record the general locations at which the different stratigraphic levels are emplaced in the spoil zone during the mining/reclamation period and, in particular, the location and method of protective emplacement of the highly noxious materials.

3. Determine or estimate the sources and qualities of waters (e.g., infiltration, runoff, groundwater) expected to reenter the spoil zone.

4. Continuously plan for monitoring during the premining, operational, and postmining periods.

This "before-during-after" approach is applicable to proposed mining operations. However, for many existing mines with little or no monitoring history, only the "after" approach is applicable. The methodoloy presented here is applicable to either of these general approaches, depending on whether the potential pollution sources under consideration are predicted for the future at a proposed mine or are actually present at an existing mine.

Even without drilling, sampling, and analysis, tentative prediction of types of pollutants and associated pollution problems may be possible if information is available on the stratigraphic sequence of rock types that will be encountered during mining.

Sedimentary rock types that overlie or are interlayered with the coal seam and portions of the coal seam itself are likely to become part of the spoils. Therefore, knowledge of the overburden rock types and their stratigraphic distribution is a general indicator of the types and perhaps relative importance of certain potential contaminants that will exist in the future spoils. In general, each rock type has a characteristic positive or negative pollution potential. Each rock type has characteristic mineral or chemical constituents, permeability, solubility, and other properties that tend to contribute pollutants. Each rock type also has characteristic properties such as adsorption, ion exchange, and filtration that tend to remove pollutants from water solutions.

Without drilling, determining or predicting the types and stratigraphic (vertical and horiztonal) distribution of the rock and associated pollution potentials is often possible by local geologic reconnaissance in combination with a review of available geologic reports and maps. The sedimentary rock types that are commonly in sequence with coal seams are clay, silt, sandstone, and limestone.

As examples, limestone ($CaCO_3$) and dolomite ($CaMg(CO_3)_2$) may be highly soluble depending on pH and carbonate content (and saturation state) of the water. Where carbonate minerals are present in appreciable quantity relative to sulfide minerals (e.g., pyrite and marcasite), the sulfide minerals are less likely to go into solution.

Several special classes of earth materials associated with coal typically become part of the spoils. These include partings, coal, coal refuse, and coaly waste. Partings are the generally lenticular-shaped, stratified inclusions of noncoal material within coal seams. They are primarily shale and carbonaceous shale. Coal, coal refuse, and coaly waste are geologically and chemically similar. Coal refuse is the fine coal and waste material removed during the coal preparation process. Coaly waste includes the thin coal seams, impure coal, and carbonaceous shale that may occur in the overburden and in partings between coal seams.

In some instances, these materials contain concentrations of toxic- or acid-forming constituents and, therefore, should be selectively emplaced in the spoils and perhaps specially protected to discourage mobility of potential pollutants. Protection against mobilization may consist of isolation from contact with water or air and possibly the use of clays with high ion-exchange or adsorption capacity to remove any mobilized pollutants from solution. In addition to being in or adjacent to the coal seams being mined, these coal-related potential contaminants may also include associated thin coal or carbonaceous seams in the overburden. Such thin or impure zones are uneconomic or impracticable to mine. During mining, they may be backfilled with other overburden material as part of the mixed spoil material. Test drilling, sampling, and analyses before mining will indicate which of these coal-related materials should be segregated and protected within the spoil zone.

In some instances where these coaly materials are stripped, they are stockpiled as byproducts of coal handling and processing. The stockpiles may be temporarily placed before disposal in the spoils of the active mine, or permanently located on the surface. These temporary or permanent stockpiles are another potential source of pollutants and are discussed at the beginning of Section 3 in the subsection titled Stockpiles. This discussion should be consulted for additional information on the pollution potential of partings, coal, coal refuse, and coaly waste. Coal wastes buried within the spoils can become sources of trace element pollution, depending upon the minerals contained in the coal. Potential pollutants may include soluble salts with sulfates of calcium, magnesium, and sodium predominating. Most spoils in the West also contain appreciable quantities of calcium carbonate. Normally, very few readily soluble chlorides, carbonates, or bicarbonates are present. Also, concentrations of phosphorous in forms available to plants are normally low in the spoils and overburden. Shales commonly contain appreciable exchangeable ammonium nitrogen when weathered. Nitrifying organisms are scarce at depths of about 8 to 10 meters because of lower soil temperatures. Consequently, nitrate forms of nitrogen predominate in the upper levels and ammonium-nitrogen predominates at the lower levels.

Methods for Predicting Spoil Groundwater Quality--

The literature reviewed concerning spoil-water quality prediction techniques involved site-specific studies at coal mines in Montana, Colorado, and North Dakota. The studies reviewed revealed two general trends in spoil-water quality predictive methods.

One approach involves measuring water-soluble constituents in the spoils and relating these values to observed spoil-water quality at the respective mine. This method assumes that spoil-water quality is largely a function of the readily soluble constituents in the spoils that are easily leached by groundwater. Research efforts reviewed that followed this approach are Dollhopf et al. (1979, 1981), Van Voast, Hedges, and McDermott (1978), and McWhorter et al. (1979). Work done by each of these research teams is summarized in this section. This spoil-water quality prediction method is the procedure most frequently used in the western United States.

The second approach to predicting spoil-water quality is based on an understanding of the chemical processes responsible for the evolution of spoil-water quality, which is the basis for calculating the ultimate water quality. The researchers involved in developing this predictive method are convinced that the saturation extract method estimates only the short-term spoil-water quality. Their calculations include the long-term salt generation capacity of spoil waters (Fred C. Hart Associates, 1981). The work on this prediction method is primarily being conducted within the Fort Union Region of Western North Dakota by numerous researchers. Their research work is also summarized in this section.

Van Voast et al. (1978) evaluated data obtained from column leach tests and saturation paste extracts of spoil materials to determine if a method could be established for predicting spoil-water quality. The constituents that were observed in the data collection phase were specific conductance, sulfate, magnesium, sodium, and calcium. Comparison of column leach test data with saturated paste extract data indicated that concentrations of major ions in saturated paste extracts were very similar to the values obtained for the first pore volume of extract obtained from column leach tests. The cost of column leach tests is much greater than obtaining saturated paste extracts. Therefore, with the similar concentrations and disparity in cost, Van Voast et al. recommend using saturated paste extracts for continued work on the prediction of spoil water quality. Also, analysis of saturated paste extracts is a commonly required overburden analytical technique in the western United States with data already available at various mine sites.

Van Voast et al. (1978) utilized saturated paste extract analyses and spoil-water analyses from Big Sky and Decker mines for the continued search for a spoil-water quality predictive tool. Van Voast et al. note that, "The overburden values were equally or more diverse than those of the spoil waters but were generally of similar chemical type." With the large range in the data, statistical methods were used to determine if a relationship could be developed between the overburden saturated paste data and the observed spoil-water quality for each mine site. The mean cation concentrations observed in spoil wells and from saturated paste extracts from overburden samples at Big Sky and Decker mines have been graphically summarized.

Van Voast et al. (1978) state:

> Because of the diversities of spoils-water and extract qualities, statistical methods were employed toward comparisons that might lead to use of extract chemistry for predictions of spoils-water quality. Nomographs comparing idealized statistical distributions of calcium, magnesium, and sodium in overburden extracts and in spoils waters at the Big Sky and Decker Mines were generated during the study. From these, probable ranges of log-normal mean concentrations of calcium, magnesium, and sodium may be predicted for spoils waters at proposed mines where saturated-paste-extract analyses have been conducted on overburden. A similar attempt toward predicting specific conductance through statistical correlations did not appear successful.
>
> The nomographs provide a very general means at cation predictions. Additional data such as sulfate analyses of paste extracts, more spoils-water quality analyses from the Big Sky and Decker Mines, and similar data from other mines may allow refinement of the nomographs toward greater precision.

In later attempts to predict spoil water quality, Van Voast and Thompson (1982) have utilized saturated paste extract concentrations (major constituents) as direct additions to concentrations in nearby groundwaters, assuming that salinities of reentering groundwaters would also contribute to spoil water quality. In current research, Van Voast and Thompson (personal communication, 1982) are comparing saturated paste analyses using distilled water with paste analyses using water from coal field aquifers.

Dollhopf et al. (1979, 1981) conducted research at Rosebud mine in Montana in an attempt to develop a predictive technique for trace metal concentrations in spoil groundwaters. Overburden geochemical data from extracts using DTPA acid and column leach methods were evaluated during the study. All DTPA extract trace metal concentrations were greater (sometimes 1,000 times greater) than values produced from column leach extracts. This was expected because the DTPA extraction technique is more rigorous than water leach extraction and the DTPA method is intended to evaluate the concentrations of elements available to plants (the western states generally require overburden trace metal analyses on extracts using the DTPA methodology).

When the overburden trace metal analytical data from both extraction techniques were compared with spoil-water quality observations in the area, the column leach data were found to be most similar to the values observed in the spoil groundwaters. Table 4-2 compares trace metal concentrations from column leach and spoil water at Rosebud mine.

Dollhopf et al. (1981) summarize the study effort to develop a technique for predicting trace metal concentrations in spoil waters as follows:

> Examination of the water column extracted chemistry and corresponding water well chemistry indicate that leachates from columns may provide predictions of postmine water quality. It should be clearly noted that the statistical means and ranges for these comparisons between column leachates and waters from wells often differed by as much as a factor of ten [Table 4-2]. Part of this difference can be attributed to sampling and lab error. Certainly, the leaching column technique is not a perfect simulation of the in situ groundwater system, so the technique itself introduces error. However, trace element concentrations in column leachates were comparable to concentrations in waters from wells to a degree which indicates the potential exists to judge which overburden materials would be most suitable for aquifer reestablishment. However, comparisons of water leachate metal concentrations and in situ groundwater quality would have to be correlated at many mines with contrasting chemical conditions to verify the usefulness of this method. Column leaching techniques are slow, expensive, and may not be practical for premine studies. An investigation should be initiated to determine whether a water saturated paste extract, which is performed on a routine basis, could provide similar trace metal levels as those attained from column leachates.

McWhorter et al. (1979) examined the relationships of the chemical composition of spoils to the observed quality of spoil waters at Edna mine in Colorado. In their study, McWhorter et al. used saturated paste and one-to-one dilution extracts to characterize the soluble constituents in spoils available for leaching by groundwaters.

Table 4-3 shows the results of determinations of specific electrical conductance (EC) on saturation extracts prepared from drill cuttings and spoil

TABLE 4-2. COMPARISON OF TRACE ELEMENT CONCENTRATION (ppm) IN LABORATORY COLUMN LEACHATES AND IN WATERS FROM WELLS IN OVERBURDEN AND SPOILS AT THE WESTERN ENERGY ROSEBUD MINE NEAR COLSTRIP, MONTANA (after Dollhopf et al., 1981)

Trace Metal	Soil Water Column Leachate Concentration (n = 25)[a]		Observation Well Data				Recommended Maximum Permissible Concentration in Public Water Supplies[b]
			Overburden (n = 16)		Spoils (n = 10)		
	Mean ± S_x	Range	Mean ± S_x	Range	Mean ± S_x	Range	
Mn	0.10 ± 0.22	(<0.01-1.09)	0.077 ± 0.074	(0.055-0.252)	0.424 ± 0.129	(0.272-0.710)	0.05
Cd	c	(<0.001-0.043)	c	(<0.005-0.014)	c	(<0.005-0.020)	0.01
Cu	0.021 ± 0.022	(<0.01-0.04)	0.023 ± 0.010	(0.005-0.038)	0.033 ± 0.019	(0.012-0.075)	1.0
Pb	c	(<0.001-0.003)	c	(<0.01-0.025)	c	(<0.01-0.01)	0.05
Zn	0.009 ± 0.005	(0.002-0.026)	0.093 ± 0.112	(<0.005-0.377)	0.220 ± 0.241	(0.022-0.712)	5.0
Ni	0.040 ± 0.047	(<0.01-0.23)	0.013 ± 0.006	(<0.01-0.018)	c	(<0.01-0.01)	--

Notes:

[a] n = number of samples.

[b] U.S. Department of Health, Education, and Welfare (1962).

[c] Many values were reported as less than (<) the indicated range, indicating a concentration less than technique sensitivity.

samples compared to drainage from spoils issuing from drains and at monitoring point C5. The values indicate a strong similarity between the average EC values measured on the saturated paste extracts and the values observed for spoil waters. The standard deviations for each set of analyses indicate quite a range of observations. This suggests that the use of EC values from spoils or cuttings would only be valid as an indicator of average spoil-water quality and that multiple EC measurements of the spoils or overburden are also necessary.

Table 4-3. COMPARISON OF ELECTRICAL CONDUCTIVITY OF SPOIL, OVERBURDEN, AND SUBSURFACE WATER (after McWhorter et al., 1979)

	Spoil	Drill Cuttings	Drains	C5 Monitoring Point
Average EC (μmho/cm at 25°C)	3,100	3,000	3,400	3,400
Number of Samples	14	5[a]	58	31[b]
Standard Deviation	930	430	720	430

Notes:

[a] Samples were prepared by compositing, by depth interval, samples from four locations along an active highwall.

[b] Regular monthly samples from October 1973 to June 1976 from C5 monitoring point.

McWhorter et al. (1979) evaluated the accuracy of measuring EC on 1:1 extracts for predicting the specific electrical conductance of spoil waters. They found measurements of EC on 1:1 dilution extracts much less reliable than saturated paste extracts.

McWhorter et al. (1979) also evaluated the relationship of measurements of the dominant constituents (sodium, calcium, magnesium, potassium, HCO_3, chlorine, and SO_4) on 1:1 dilution and saturated paste extracts with values observed for spoil waters. Table 4-4 compares the analytical data obtained from the two spoil extract methods and actual spoil-water quality values. The data indicate an excellent relationship between the relative composition of the major constituents and the conclusion may be drawn that, for Edna mine, either extraction method (1:1 or saturated paste) would provide an acceptable prediction of spoil-water quality. The hydrogeologic circumstances at Edna mine are such that all recharge to the spoils is from vertical deep percolation, with no horizontal component of groundwater flow into the spoils.

In summary, the spoil-water quality prediction technique involving analyses of specific electrical conductance (EC) and the major ions on saturated paste extracts appears to be the easiest and quickest way to estimate average spoil-water quality. Although this method has been successful at several mine sites, there have also been problems. Researchers should use large sample sizes and acknowledge that, at best, these data will only give an average estimate of spoil-water quality. Whenever possible, the results of saturated paste analyses should be compared to spoil-water quality values from similar geohydrologic environments in the area to assure that a valid relationship exists between analyses of saturated paste extracts and spoil waters.

TABLE 4-4. COMPARISON OF COMMON ION CONTENTS IN EXTRACTS AND MINE DRAINAGE (after McWhorter et al., 1979)

	Percent of Total						
	Ca	Mg	Na	K	HCO_3	Cl	SO_4
Saturation Extract - Spoil	3.3	18.8	3.5	2.4	15.4	1.3	55.2
1:1 Extract - Spoil	14.3	8.3	2.3	--	5.3	0.4	69.4
Subsurface Drains	12.6	8.9	3.1	0.8	10.0	0.1	64.4
C5 Monitoring Point	12.1	8.5	3.8	0.6	6.7	0.2	68.2

The following discussion of groundwater quality projection techniques is taken from a report to the Office of Surface Mining, Region V (Fred C. Hart Associates, 1981).

Research in and around the Fort Union Coal Region of Western North Dakota relating to the impacts of surface coal mining on the land and water resources of the area has been extensively studied by Moran and Cherry (1977); Moran, Groenewold, and Cherry (1978a); Moran et al. (1978b, 1979); Groenewold (1979); Groenewold et al. (1980); Palmer and Cherry (1979); and M.G. Croft and his coworkers (personal communication, 1981). Croft's research for the USGS involved Gascoyne mine near Bismarck, North Dakota, while the remaining researchers investigated five other sites in North Dakota.

The overall objective of the work performed by Moran, Groenewold, Palmer, and coworkers is to aid in the reclamation of surface-mined lands by developing a basis for predicting their soil and groundwater chemistry. The term "engineered cast overburden" (ECO) has been coined to refer to an approach to reclamation of surface-mined lands and is defined as reconstruction of the entire landscape rather than just its surface form and soil (Moran, Groenewold, and Cherry, 1978a). This approach to assessment of postmining groundwater chemistry requires a thorough understanding of several geochemical and mining processes as well as the development of a number of analytical techniques. Materials comprising the overburden had to be identified and evaluated. The inventory involved soil mapping, geologic mapping, development of a three-dimensional materials framework, geohydrological studies, and geochemical studies to delineate the properties of the materials. Understanding the form and internal structure of material deposited by various types of mining equipment and techniques was necessary to determine which equipment and procedures could be used to obtain desired physical and chemical characteristics at desired locations within the cast overburden.

In the study by Moran, Groenewold, and Cherry (1978a), the chemistry of overburden core and cutting samples was analyzed at five mine sites. The constituents evaluated included texture, oxidation state, pH, electrical conductivity (EC), and carbonate content. Over 500 saturation extracts were analyzed.

Additionally, the quality of the groundwater was evaluated. Water quality parameters that were analyzed included pH, EC, TDS, alkalinity, hardness, and the eight major cations and anions. Relationships between overburden type and water quality were evaluated.

Four significant chemical property trends of overburden materials were identified from the analyses: (1) materials having a higher clay content have a greater tendency to be sodic; (2) the proximity of the materials to the land surface, regardless of texture, has a strong influence on their chemical characteristics; (3) the direction of groundwater movement in the near-surface zone in large part controls the chemical characteristics of the materials; and (4) it is very likely that geochemical variations in the materials of the original environment of deposition and interaction with groundwater flow have a strong influence on the chemical characteristics of the overburden materials (Moran, Groenewold, and Cherry, 1978a).

To determine the postmining quality of groundwater, the authors based their analysis on the assumption that "an interpretive framework that adequately accounts for the observed water chemistry in the natural overburden will have some applicability in the analysis of salt generation and accumulation in reclaimed land" (Moran, Groenewold, and Cherry, 1978a). To be valid, this framework must account for several variables, including the existence and variation of the predominant ions in the subsurface water, the pH of the water, variation in the concentration of total dissolved solids of the groundwater, and the partial pressure of dissolved carbon dioxide in the water (Moran, Groenewold, and Cherry, 1978a). It must also account for changes in water chemistry that occur as the water infiltrates and migrates through the underlying vadose zone into the groundwater zone.

Several important reactions that can determine the postmining groundwater quality were found (Moran, Groenewold, and Cherry, 1978a):

1. Production of carbon dioxide in the soil zone by oxidation of organic matter
2. Oxidation of pyrite
3. Dissolution of carbonate minerals
4. Precipitation of gypsum

5. Dissolution of gypsum

6. Cation exchange

7. Sulfate reduction.

The most common groundwater composition in tertiary deposits in Western North Dakota (water with dominant concentrations of Na^+, HCO_3^-, and SO_4^{-2} ions) is generated by various sequences of the seven geochemical processes indicated above. Additionally, in cast overburden, the release, transport, and accumulation of Na^+ depends on the occurrence of calcite and gypsum in the overburden and the cation exchange capacity of the overburden. The occurrence of gypsum depends primarily on the occurrence of pyrite and the rate and frequency at which water containing dissolved oxygen contacts pyrite and then evaporates or transpires. All of the important geochemical processes that determine the chemistry of groundwater in the study areas are primarily operative above the groundwater; the chemistry of the groundwater, regardless of the age and distance that the water has traveled, is determined by the geochemical processes that occur during recharge (Moran, Groenewold, and Cherry, 1978a).

During exceptional recharge events, gypsum and other soluble salts are transported to the water table, resulting in high concentrations of sulfates. The existence of gypsum is the result of the concentration of calcium sulfate due to evapotranspiration of groundwater in the unsaturated zone. The existence of the calcium and sulfate can be primarily attributed to the oxidation of pyrite and the dissolution of calcite (Groenewold et al., 1980).

The important result from studies by the authors was the following conclusion: "... an understanding of the runoff-infiltration relationships within the landscape combined with a knowledge of the distribution of near-surface permeability and mineralogical constituents such as pyrite, calcite, gypsum, clay minerals with Na^+ adsorbed on the exchange sites provides an adequate basis to evaluate EC and SAR of the cast overburden. In order to predict how the materials will behave in a reconstructed landscape, it is necessary to know where in the landscape each type of material will be placed and what the configuration of the landscape will be. In this way, the subsurface hydrologic regime can be projected and the resulting liberation of available ionic constituents by weathering and transport or nontransport of these constituents can be estimated" (Moran, Groenewold, and Cherry, 1978a).

The major limitation to understanding the postmining groundwater quality in this type of analysis is accurate determination of the amount of carbonate, pyrite, and gypsum in the overburden. Although existing analytical techniques may show an absence of carbonate, pyrite, or gypsum, this cannot be taken as positive evidence of the absence of these minerals. Thus, long-term postmining groundwater quality prediction is extremely speculative, at best, with respect to these minerals and their relationship to total dissolved solids concentrations. Several areas of additional research must be explored before the EC geochemical model can be confidently used as a predictive practical tool in designing reclamation programs to protect groundwater quality from surface mining impacts. One is the development of analytical techniques to evaluate the amount of potentially soluble calcite and gypsum and potentially oxidizable sulfide (pyrite) present. In addition, a methodology needs to be developed to adequately evaluate cation exchange capacity and to determine which cations are available for exchange. The model itself needs to be further tested, modified, and sharpened as a predictive tool (Moran, Groenewold, and Cherry, 1978a). Also, the composition of the gas phase in the spoils must be determined to evaluate the extent of pyrite oxidation (Palmer and Cherry, 1979).

Currently, a computer model is being developed by Groenewold et al. (1980) to predict the postmining water quality. This model uses an iterative technique to determine the equilibrium distribution of the aqueous and solid phases. The reactions described above are used in the model (Groenewold et al., 1980).

Research that has been conducted by Croft and coworkers is similar to that of Moran and coworkers. Croft has been working at Gascoyne mine in North Dakota. The existing groundwater hydrology at Gascoyne mine is very complex, as it is at the other North Dakota mines that were studied. Croft and coworkers are also attempting to quantify the existing, undisturbed geohydrologic system at the mine to determine what reactions are occurring between the groundwater and the various constituents of the strata. This allows them to understand the reactions that are occurring naturally and extrapolate these mechanisms to reactions in overburden material.

Groundwater quality in the undisturbed recharge area at Gascoyne is extremely variable. The water has a very low sulfate and total dissolved solids content. As the water migrates southeast toward the mine, both of these constituents increase dramatically until the sulfate content reaches a few thousand parts per million upgradient of the mine. In one area where the lignite outcrops and a marshy area has formed, a sulfate content of up to 16,000 parts per million has been found. This is beyond any influence of the mining operation. The high sulfate concentration has been hypothesized to be from the dissolution of gypsum (D. Fisher, USGS, personal communication, 1981) or the oxidation of pyrite in the lignite along with cation exchange (R. Houghton, USGS, personal communication, 1981). In general, the evolution of the groundwater is thought to be a result of the same processes identified by Moran, Groenewold, and Cherry (1978a). In addition, two other reactions have been found to have significant effect in the Gascoyne area. These are the high cation exchange capacity of the Gascoyne lignite, which is one to two orders of magnitude greater than the exchange capacity of the clays, and carbon dioxide production from the lignite (D. Fisher and R. Houghton, USGS, personal communication, 1981). The high CEC has the same effect as before, removal of calcium from the system so that the saturation limit of gypsum is not reached. The carbon dioxide production limits pyrite oxidation because oxygen is displaced from the system. At one testing site, the gas phase consisted of 18 percent carbon dioxide and almost 80 percent nitrogen. In this situation, pyrite oxidation is negligible. Houghton (USGS, personal communication, 1981) has hypothesized that the carbon dioxide is produced from the lignite and from organic material in the strata below. As the water in the lignite (which is high in carbon dioxide) moves laterally into the spoil material, carbon dioxide is released and moves up through the spoil material, displacing oxygen entrapped during mining. Again, pyrite oxidation is reduced. Only the pyrite in the lignite seams, or highly carbonaceous shales that underlie the lignite, appears to be susceptible to extensive oxidation. Pyrite in the overburden, which has been found near the surface subsequent to disturbance, has shown no signs of oxidation over a period of up to a year (R. Houghton, USGS, personal communication, 1981).

To attempt to project the postmining water quality at Gascoyne mine, the foregoing reactions and considerations are being incorporated into a computer model. This model will attempt to predict what the quality of the postmining groundwater will be, based upon equilibrium of these reactions in the system (R. Houghton, USGS, personal communication, 1981). Nothing has yet been published on the postmining groundwater quality at Gascoyne because the exact nature of the geohydrochemical system remains uncertain.

In summary, the ongoing research in North Dakota has centered on a more indepth understanding of the geochemical reactions that could occur in the overburden. These reactions and interreactions that occur during the evolution of the postmining groundwater quality are extremely complex. The system is dynamic and no single equation can define it. Changes in sulfate levels will occur in the groundwater in response to recharge from major precipitation events. If piping in the overburden occurs as the overburden settles, increased oxygen levels in the spoils may result in increased oxidation of pyrite. This process has been found to occur up to 5 years after mining was completed (Palmer and Cherry, 1979). No analytical technique has been developed to assess the long-term impacts to the groundwater system by mining. However, the ongoing research in North Dakota should yield extensive insight into quantifying these impacts. The geohydrological setting is complex and no simple answer will suffice to quantitatively assess postmining impact.

Monitoring Needs--

Knowledge of the general chemical characteristics of the regraded soil is needed. Information is especially needed on the type, concentration, and distribution of elements and compounds that can become sources of groundwater pollution, particularly for those zones of regraded spoils in contact with free underground water, whose leachate possibly could contribute pollutants to the groundwater system.

Alternative Monitoring Approaches--

The preferred, or recommended, monitoring approach is to be selected from nonsampling and sampling alternatives.

Nonsampling methods--Records of the location and amount of spoils that are emplaced during the monitoring program are desirable. Special attention should be given in these records to disposition of materials that have significant pollution potential and to any protective measures taken to isolate certain potentially toxic or acid-forming materials from water, air, and other conditions or processes that may tend to introduce contaminants to the hydrologic system.

Maps can be compiled on a monthly basis indicating both the location and elevations of spoil material in the reclaimed area. Gross volumes or weights of material can be estimated. A photographic record of the face of the spoils in the pit can be maintained. Such a record can substantiate, for example, that more consolidated formations with few contaminants are selectively placed in the bottom of the spoils.

Sampling methods--It would be highly advantageous to identify and locate potential pollutants and their in-place stratigraphic position during the premining exploration phase and then, based on this information, formulate and execute a systematic reclamation plan including special emplacement or protective isolation in the spoil zone of materials with high potential for contamination. This effort can minimize later pollution. Also, the resulting records on material types and their systematic placement in the spoil zone probably will be less complex and more informative than information obtained solely by postmining probing in the heterogeneous spoil mass.

The composition of materials contained in the spoils should be determined. Random composite samples can be taken at points on a grid covering the entire spoil area. The spacing of the points on a second sampling pass should be determined by the variability and toxicity of material encountered during initial sampling. Such a system has an advantage of simplicity but would be time consuming and costly.

Alternatively, a priority sampling scheme can be employed. The objective would not be to characterize the entire area of spoils by one or more elements or compounds, but rather to delineate selected zones containing pollutants that due to their location or toxicity have a relatively high potential for introducing new pollutants or increasing existing concentrations of pollutants in the groundwater system.

These selected areas can first be delineated on the basis of their relation to existing or predicted water table elevations within the spoil materials. Potential contaminants that are readily water-soluble are more likely to be released from the spoils if they are in the saturated zone. In contrast, those potential pollutants that are mobilized by oxidation processes are more likely to be released in the vadose zone above the water table. The potentially saturated and unsaturated zones that are delineated can be sampled in two stages. Initially, grid points spaced about 300 feet apart can be sampled. Samples should be taken at each point throughout the entire depth of spoils at no less than 5-foot vertical intervals (M. Hulbert, personal communication, 1980). Sampling can be at closer intervals if particularly toxic materials are encountered. The subject of spoils sampling in areas of potentially toxic material placement has not been addressed by State regulations.

The sampling frequency of solids in spoils is difficult to specify. In part, it depends on the variability of materials encountered in the pit, including overburden, partings, and coaly waste. Part of this variation will be known at the time of mining due to the quality of coal desired and for purposes of reclamation. The frequency of sampling can be related to this variability. During the first year, monthly grab samples should be collected.

After the first year, the frequency can be adjusted based on past experience and the dynamic chemical characteristics of regraded spoils.

Spoil samples should be analyzed for pH, electrical conductivity, total soluble salts, soluble cations, base saturation, sulfate, nitrate, total nitrogen, and total organic carbon. Tests should be run on saturation extracts for powdered samples. In addition, boron and fluoride levels should be determined. The content and character of pyrite or other forms of iron sulfide largely control the potential acidity of water contracting spoils and should be evaluated. The soluble calcium content of the spoils also exerts a controlling influence on the pH.

Drever, Murphy, and Surdam (1977) discuss trace elements associated with the Wyodak coal seam at Black Thunder mine. Vanadium, manganese, nickel, copper, zinc, arsenic, selenium, lead, barium, cadmium, chromium, iron, molybdenum, and silver should receive groundwater quality monitoring priority due to their importance for water use and their probable relative mobility in soil-aquifer systems.

Organic chemical content of certain materials in the spoils can be substantial. This is particularly true for coaly waste and shales. A gross indication of the composition can be obtained by determining the total carbon and total nitrogen content. If specific organic chemical constituents are found in spoil groundwater, then solid spoil materials can be sampled for specific constituents later.

The radiological content of spoils should be grossly evaluated periodically by determining the uranium and thorium contents. Samples can also be analyzed for alpha, beta, and radium-226 activity.

Changes in water quality may be the first detectable indication of release of contaminants from the spoil materials and of the particular contaminant species being released. Thus, it may be desirable to sample and analyze water from zones within the spoils and immediately downgradient along spoil flow paths.

Costs for Step 3 include labor for gathering existing information, mapping spoils, and sampling; operational costs for mapping and sampling supplies and spoil analyses; and capital costs for soil samples.

Recommendations--

For proposed mining sites, information should be obtained on the distribution of in-place geologic strata that will be disturbed and replaced during mining and reclamation. During conventional exploratory drilling, the respective strata and their lateral and vertical distribution, including overburden, coal, and adjacent underburden zones, should be sampled, tested, observed, and chemically analyzed to obtain a three-dimensional appreciation of potential pollutant types. As many of the samples as possible should be obtained by coring. Appropriate plans for systematic removal and emplacement in the spoil zone should be incorporated in the mining plan. In particular, selective protective emplacement in the spoil zone should be planned for any previously identified constituents that may be highly contaminating.

For monitoring programs that start after the premining exploratory period, exploration information should be reviewed and interpreted in terms of potential pollution type and location of materials that have been emplaced in the spoil zone.

Existing information on the location and nature of backfilled spoil material should be obtained and arrangements should be made with the mining company to receive ongoing information of this type. If such data are not being gathered, backfilled areas should be mapped and photographed, including items such as spoil location, elevation, and composition. These maps should be updated frequently, possibly monthly.

The composition of spoil materials should be determined using a priority sampling scheme with sampling frequency depending on the variability of spoil material and the rate at which an area is backfilled. Samples should be analyzed for the constituents discussed earlier.

Step 5. Evaluate Infiltration Potential

Monitoring Needs--

Infiltration is the combined process of the entrance of water at the soil surface and its subsequent downward movement through near-surface soil media. Water that infiltrates the land surface and passes the near-surface zone, where it may be subject to return to the surface by capillary action, evaporation, root capture, or other processes, will subsequently percolate generally downward toward the groundwater zone. The infiltrating water may carry contaminants from surface sources and as it percolates through the vadose zone, it is subject to various processes that either increase or decrease its contaminant load.

Infiltration is affected both by the condition of the surface and the nature of the soil material. A large portion of the spoils at the mine sites in the study area is fine-textured (excluding large rock fragments) material derived from shale and siltstone with a high clay fraction (often above 20 percent). Furthermore, the characteristically rapid decomposition of shale when exposed to weathering releases salts that tend to inhibit flocculation and the formation of soil structure. If the materials have an exchangeable sodium percentage greater than 15 (i.e., sodic), as they often do, they may form a soil surface essentially impermeable to water.

Infiltration rates on spoil materials may vary from as high as 20 inches per hour (alluvial material) to 0.2 inch per hour (shale material). An average infiltration of about 0.5 inch per hour is common in spoils with high shale and clay components (M. Bishop, personal communication, 1981).

Reclamation regrading and surface treatments (pits, furrows, berms, etc.) create depressions for surface water retention, resulting in a trapped supply of water at the soil surface that might sustain infiltration for long periods.

Retention basins, however, often become sealed by fine material washed in by surface runoff. Their effective life may be only a few years under the best conditions. In areas where underground fires have occurred, infiltration may be greatly influenced by cracking and caving at the surface that allow the entry of free water. If the mining operation is efficient, these areas are small and short-lived and occur infrequently.

Stream channels reconstructed across spoil material are an important source of possible groundwater pollution from infiltrating waters. Creeks that are ephemeral in their natural state will probably also become reestablished as such and will have a high potential for contributing significant amounts of surface water to the groundwater system.

Infiltration capacity is important in characterizing the hydrologic behavior of spoils. Information on infiltration is needed to supplement other data such as precipitation, snowmelt, evaporation potential, and geochemistry necessary to classify the potential of spoil materials to pollute the groundwater system.

Alternative Monitoring Approaches--

Nonsampling methods--Infiltration capacity should be estimated with double-ring infiltrometers or sprinkler-type infiltrometers. Field infiltrometer tests are useful for comparing differences of magnitude between sites and for irrigation purposes, where the supply of water at the soil surface is steady, but they cannot be relied upon for quantitative representation of actual infiltration of natural precipitation.

Sprinkler-type infiltrometers are generally preferred over the ring type for field tests. They more closely approximate natural rainfall, provide a measure of surface runoff potential, and with some devices give estimates of erosion potential. They are also difficult to operate, however, require considerable auxiliary equipment, and are expensive. The ring devices are very simple and are a quick means of obtaining relative values of infiltration capacity for different sites.

Measurement sites can be chosen randomly or selected on the basis of previous information. Ideally, sampling should be completely random or systematic with random starts, but this requires inordinate effort to characterize a large area. Interpretation is complex because of point-to-point variability. Stratification would help reduce variability if an average were sought for an entire area.

Representative sites for infiltration studies can be based on chemical and physical characteristics. For example, a representative balance might be used in distributing sites between sodic areas and saline areas, which are more permeable.

Sufficient testing should be done to achieve a reasonable degree of precision; 10 percent of the mean final infiltration rate (fc) at the 95-percent confidence level is desirable. For most spoil materials, the final rate is obtained within 2 hours (U.S. Bureau of Reclamation, 1977).

Infiltrometer data can be used with precipitation measurements and historic records of precipitation to estimate the maximum probable infiltration under the prevailing climatic conditions at a mine site.

Sampling methods--Infiltration capacity can be estimated by laboratory tests of spoil permeability. These tests, however, are of doubtful value because of the disturbed nature of the samples, their small size, and the associated difficulty of obtaining representative samples.

Recommendations--

Infiltration capacity should be determined using a double-ring infiltrometer because of economics and ease of obtaining data quickly from a large number of sites. Sites should be selected on the basis of information gathered in Step 3, Identify Potential Pollutants. Precipitation data can be obtained from existing records for the area.

Costs for Step 5 include labor for infiltration measurements and data collection and capital costs for ring infiltrometers.

Infiltration is the net downward movement from the surface. Water that returns to the surface rather than percolating through the topsoil and spoils is not included in this definition. Continuous application of water to the spoils surface, such as from a pond or stream, may establish saturated flow, which is a measure of the rate that water will percolate downward through the spoils to the water table or to a saturated zone that drains the spoils mass. Assuming that the storage capacity of the spoils has been met, in unsaturated conditions the water moves under the force of gravity. Typically, however, in the water-deficient areas of the West, water is not continuously applied to spoils. Thus, during dry periods, water that has not penetrated beyond shallow, near-surface zones may return to the surface or to the atmosphere due to upward capillary movement, evaporation, plant consumption, or other processes.

Much research has been done on agricultural soil infiltration, but relatively little on spoils infiltration. The following review of research on soil-water relations in spoils, quoted from Schafer et al. (1979), describes infiltration, runoff, erosion, and other interrelated variables that may be useful in monitoring contamination from spoil resources:

> Low infiltration rates on mine spoils cause increased runoff which can reduce plant available water, remove applied topsoil, and create sedimentation problems. Erosion and reduced infiltration are therefore major problems in arid mine land reclamation.
>
> Gilley and others (1976b, 1977a) measured runoff and erosion on native range, and topsoiled, and nontopsoiled spoils in North Dakota using a large rainfall simulator. Two storms of 1-hour duration and 2.5-inch/hour intensity were simulated. Soil loss on native range was 200 kg/ha; only 12% of the applied water ran off the plots. Water from both events moved deeply into the profile (>18 inches).

Soil loss on raw spoils was 15,000 kg/ha and 21,000 kg/ha on cultivated and uncultivated erosion plots. Runoff consisted of 66 to 74% of the applied water. Water did not penetrate significantly into uncultivated spoils and increased only in the upper 6 inches of cultivated plots. Cultivation of the topsoil/spoil interface did not increase percolation into the spoils. As slope was decreased from 17 to 6%, soil loss was reduced by about 30%. Differences in spoil texture had little influence on soil loss.

Gilley and others (1976a) found that topsoiled spoils had higher infiltration than raw spoils. However, water did not penetrate the topsoil/spoil interface. Cultivation of the interface to increase contact did not influence percolation into the spoils. Restricted percolation of water below the topsoil zone was also observed by Dollhopf and others (1977). It was suggested that physical and chemical treatments to decrease compaction and minimize clay dispersion would be necessary to increase deep percolation. Henning and Affleck (1977) in Iowa found that deep tillage of compacted spoil sublayers increased infiltration, deep water movement, and initial corn growth.

Erosion was greatest on topsoiled spoils at 74,000 kg/ha. As topsoil thickness of the treatments was increased from 25 to 61 cm, runoff decreased but erosion increased. Water content of the topsoil zone increased after the rainfall events, but no water entered the underlying spoils. Application of straw mulch decreased erosion on topsoiled and nontopsoiled plots by 93 and 84%, respectively.

Erosion was less on spoils without topsoil because a surface crust formed on the clayey sodic materials which slowed erosion. Topsoil materials on spoils were more erodible than similar undisturbed soil in part due to a loss of soil structure during the handling process (Gee and others, 1976). Water content of topsoil increased rapidly during the rainfall events.

Miyamoto and others (1977, 1978) reported that some spoils in New Mexico were nonwettable and, as a result, had slow infiltration rates. High-grade coal was identified as the source of the hydrophobic substance. Addition of ethyl alcohol significantly increased infiltration into coaly spoil by decreasing the contact angle, thus increasing capillary adsorption. Infiltration into sodic, noncoaly spoils was not affected by addition of ethyl alcohol, but was increased by adding $CaCl_2$ to the irrigation water.

Arnold and Dollhopf (1977) found that minesoils in Southeastern Montana had slower 30-minute infiltration rates than undisturbed soils. The presence of vegetation or application of topsoil signficantly increased infiltration into spoils, however. Dollhopf and others (1977) found a similar result on

> spoils at Colstrip and Savage, Montana; and Beulah, North Dakota. Infiltration on selected surface soil treatments decreased in the order topsoil/chiseled > nontopsoil/chiseled > topsoil/dozer basin. The dozer basin treatment removed topsoil from the basin area, and in addition compacted the underlying spoil. Therefore, infiltration was highly influenced by the surface material and decreased from topsoil to spoil to compacted spoil.
>
> Wyatt (1978), working with data from this study, found that infiltration rates on native range, oil spoils, and new spoils were not significantly different. Spoils and soils were predominantly sandy loam in texture and were nonsodic. Application of topsoil derives its maximum benefit when the spoils are clayey, sodic, or high in coal content. Although topsoil often increases infiltration, and can store more water than spoils, it is very erodible with a small amount of runoff and therefore must be protected during the early stages of reclamation.
>
> Arnold and Dollhopf (1977) found that the hydraulic conductivity (K) of native range soils (4.9 cm/day) was greater than all spoils studied (1.3 cm/day). Topsoiled spoils had higher K values in the topsoil zone than in the underlying soil. Drainage below the root zone of fallow native range and spoils was calculated. Assuming the soil was recharged to field capacity in the spring, 2.5 to 4.0 cm would drain in one year from spoils and native range, respectively.

Schafer et al. (1979) found in their studies in the Colstrip, Montana area that infiltration into minesoils was not slower than into natural soils as had been shown by other studies in the region (Gilley et al., 1977b; Dollhopf et al., 1977; Arnold and Dollhopf 1977; Miyamoto, 1978). Differences in infiltration rates between different sites are highly correlated with surface sand and silt content. Moderately rapid infiltration rates can apparently be attained quickly in minesoils by using nonsodic, coarse-textured surface material. Impermeable subsoil layers would be expected to eventually decrease infiltration rates (Gilley et al., 1977b).

Step 6. Evaluate Pollutant Mobility in the Vadose Zone

Monitoring Needs--

After infiltration through the near-surface zone of soils and shallow spoils to a depth below which they are not returned to the surface, pollutants, in water solution, are subject to continued downward percolation through the spoil vadose zone toward the water table. Mobility in this zone involves rates and routing of pollutant movement and changes in heads and concentration. Mobility of waterborne pollutants through the vadose zone is relatively complex because of both unsaturated and saturated flow and storage conditions and numerous conditions that may alter the chemical characteristics of the pollutant load being carried in solution. Conditions that influence direction and rates of flow, storage, and chemical characteristics in the vadose zones of spoils are likely to be more complex than average because of the heterogeneity of spoils. Monitoring of the mobility of pollutants in the vadose zone of mine spoils may be correspondingly difficult.

Whether or not waterborne pollutants remain in solution, or either temporarily or permanently drop out of solution at some location along the path of flow, is a function of various chemical-physical interactions of the pollutants and their changing environment along the flowpaths. Thus, in attempting to evaluate the mobility of pollutants, both the mobility of the water component of the solution that is the transporting agent and the mobility of the pollutant components must be considered.

Although a major concern of a monitoring program may be the movement of water in the vadose zone, accounting for the stoppage or lack of movement that relates to storage capabilities of the zone, which may be large, is also important.

Spoils consist of solid material and the intervening pore space that may retain water in storage. Porosity is a measure of the volume of water that can be stored under saturated conditions. Specific retention is the water volume content of a particular geologic material after drainage has occurred for a specified time. (Field capacity is the essentially analogous term, expressed on a weight basis, for soil.) Specific yield, or effective porosity, of geologic material is the difference between porosity and specific retention.

Low infiltration rates and the presence of restrictive soil or deeper strata have caused water deficiencies in subsurface zones in many areas of the West. Spoils that are dry or that develop water deficiencies have a potential for storage of additional water. The greater the thickness of a deficient zone, the greater the storage potential.

Figure 4-2 shows the relationship between specific retention, porosity, specific yield, and grain size of different geologic materials. Specific retention and porosity, both measures of storage capacity, are greater for finer-grained materials.

In monitoring the quantity and quality of water moving through the vadose zone of spoil to groundwater, particular attention needs to be given to sites with high infiltration capacities and/or high permeability situated in a low topographic position, extended periods of water availability at the surface, shallow depth of spoil water above the water table, and concentrations of potential pollutants within the spoils.

Pollutant constituents of the water solution move with the water but may be removed from solution by contact with certain types of rock surfaces, by intermixing with other waters, or by filtration through certain earth materials. Such reductions in dissolved load and concentration may be caused by processes that include adsorption or ion exchange, precipitation, and oxidation-reduction. The diversions and changes in rate of water movement, including storage, can also occur without accompanying changes in load or concentration of contained pollutants.

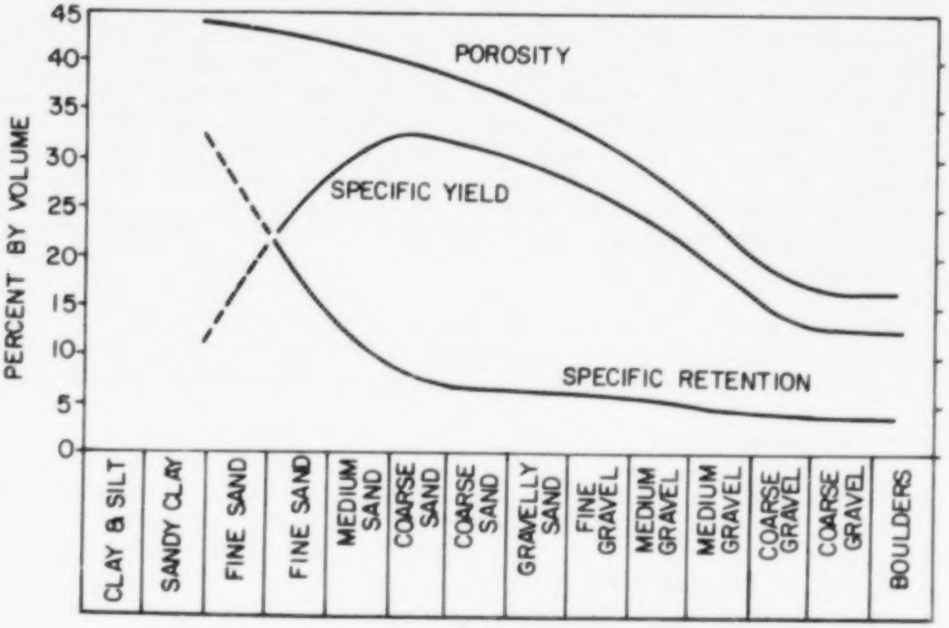

Figure 4-2. Relationship between median grain size and water-storage properties of alluvium from large valleys (after Davis and DeWiest, 1966).

Load and concentration of contaminants can be increased by removal of water from the water-contaminant solution. Water can be removed by processes that include evaporation, consumption by vegetation, filtration, and osmosis. Load and concentration of percolating solution also can be increased by dissolution of solids from the surfaces of spoil material. Materials previously removed from solution are potentially subject to redissolution when the chemical environment changes. Further, simple mixing with more concentrated solutions can increase load and concentration.

Although some of the foregoing processes may cause proportional changes in concentrations of the chemical constituents of the solution, disproportionate changes in which constituents leave or enter solution at different rates can be expected in most instances.

Alternative Monitoring Approaches--

Nonsampling methods--Development of a monitoring program for the vadose zone will require site-specific information on where monitoring is needed, what methods to use, and the intensity of sampling required.

Regraded spoil areas can be surveyed and mapped to delineate their potential for contributing water and/or pollutants to groundwater. Hydrologic, geologic, and geochemical data collected before and during the mining and reclamation phases can be evaluated. The survey requires information on hydrologic characteristics (high, medium, and low infiltration capacities), topographic position (swales, depressions, drainage channels, etc.), predominant types of material (alluvium, shale, siltstone, sandstone, etc.), chemical characteristics of the material (sodic, alkaline, normal, etc.), depth to existing or predicted future water tables, and anomalies (excessive amounts of partings, unrecovered coal, other toxic and acid-forming materials, wastes, and underground combustion).

In addition to topography and spoil type, maps should include delineations of free water surfaces (existing and future possibilities), the results of soil sampling and analyses, infiltration characteristics, and the existence and depth of water table.

Using overlays or computer graphics, critical areas of spoils can be delineated and ranked for their potential to contribute to groundwater problems. For example, an area with potentially pollutant spoil material, surface concentrations of water, and high infiltration capacity that overlies a shallow water table would be given a high priority and warrant intensive monitoring.

Sampling methods--Since water movement and any pollutants it might carry to the groundwater system will occur as unsaturated, unsteady flow, it will be necessary both to sample changes in water content and measure the pressure changes with time and depth. The following methods can be used to determine if movement of water is occurring from a pollutant source.

The three most common means of measuring moisture changes are gravimetric, electrical resistance, and neutron scattering. Changes in pressure (negative head) can be measured with pressure plates, tensiometers, and psychrometers.

For measuring moisture content, electrical resistance methods are difficult, if not impossible, to quantify with confidence. Gravimetric methods give good results but eventually destroy the sampling site and are time-consuming and labor intensive. Neutron probes and loggers also present technical and logistic problems but are a satisfactory compromise. Tensiometers, although simple, require diligent maintenance and will not give reliable results below moisture contents corresponding to pressure of about 3.4 bar. At lower moisture contents, soil psychrometers can be used instead of, or to augment, tensiometers. These devices require skill and experience to interpret accurately. They are ineffective in wet soils but give good results at lower moisture contents.

In theory, simulation of moisture flux in soil media is also possible using field- and laboratory-determined values of the necessary parameters. Models have been developed to date, however, only for homogeneous and simple layered systems and have little application to mine spoils because of the inhomogeneities in most spoils and the difficulty of obtaining the parameters required by the models.

Costs for Step 6 include labor for installation of access wells and tensiometers and for sampling; operational costs for installation; and capital costs for wells, tensiometers, a neutron logger, and chemical analyses of soil and spoil moisture.

Recommendations--

Surveys should be collected and evaluated with previously collected data to delineate and rank critical spoil areas. Based on the preceding considerations, neutron probe access wells extending through the spoil well into existing or predicted future saturated zones are recommended at critical sites. Tensiometers should be installed adjacent to access wells at three depths above the capillary fringe region of the water table at intervals of no more than 2 feet apart. Since moisture flow will be negligible at pressures less than 1 bar, psychrometers will not be necessary. The data from this monitoring can be used to document movement of water out of critical pollutant source zones.

Sampling should be conducted in two stages. Initially, all sites delineated in the survey should be instrumented with an access tube extending through the entire depth of spoil. Monthly monitoring throughout the first year will allow the most obvious nonproblem sites to be eliminated from subsequent monitoring. Questionable sites should be monitored as long as necessary to determine if they present problems or may be eliminated. The final number of problem areas is not expected to be large. Significant flow of water, under conditions of low precipitation, will occur only in the most permeable and shallow materials. Monitoring should be intensified on sites that exhibit a high potential for contributing to the groundwater system.

Additional access tubes in a second stage are recommended for critical sites. Moisture contents are assumed to be high where problems exist. Therefore, tensiometers should be installed adjacent to the access tubes to measure pressure differences for the determination of flow volumes.

The number of installations will depend upon cost, the variability encountered, and the precision desired. Standard sampling analyses that incorporate these variables should be used to establish the sampling intensity.

Step 7. Evaluate Pollutant Mobility in the Saturated Zone

Water that percolates downward through the spoils normally will enter a saturated zone below a water table that forms at some depth in the spoils. Relatively impermeable materials below the spoils support the saturated zone and limit further downward percolation. Thus, in the saturated zone, the water generally moves laterally in the direction of the hydraulic gradient. In some instances, leakage into underlying aquifers may occur.

Premining geologic strata usually contain groundwater. Coal seams are important water-bearing aquifers in many areas. After removal of overburden and coal and backfilling of spoils, the original aquifers are not present in the spoil zone. In the nonmined zone abutting the spoils, however, extensions of the original aquifers in their natural undisturbed condition are likely. Water will tend to enter the spoils from undisturbed zones. Thus, water in the saturated part of the spoil zone may be derived not only from percolating surface water, but also from undisturbed adjacent areas.

Because of their heterogeneity and lack of stratification to serve as confining layers, spoils tend to contain unconfined groundwater only. Van Voast, Hedges, and McDermott (1978) found, however, that at dragline operations in Southern Montana coarse rubble tends to roll down the sides of spoil piles during backfilling and form a permeable basal aquifer. Tests indicated that these stratified aquifers that are formed at the level of the lowermost mined coal seam are confined under artesian pressure. In such situations the spoils may contain both a confined, basal aquifer and an overlying unconfined aquifer.

Water percolating downward through the spoils from the surface is not likely to enter the confined aquifer. Instead, water enters the confined strata from corresponding undisturbed aquifers in adjacent areas. Thus, the separated aquifers may contain water of considerably different quality due to different sources.

Moran et al. (1979) report that data presented by Rahn (1976) indicate that spoil aquifers at the sites of two pumping tests in Wyoming are under water table conditions. At locations where coal to be mined is above the water table, relatively little opportunity exists for appreciable lateral recharge into the spoils from adjacent undisturbed areas.

To facilitate mining, pit water is usually maintained at a low level by pumpage that commonly causes a drawdown of the water table in adjacent areas. Considerable time may be required after mining ceases before the water table recovers in the spoils to a level that is in appropriate equilibrium with recharge and discharge conditions. As the water level changes, the amount of soluble materials available for solution changes, affecting postmining water quality.

Below the water table, less oxygen may be available than in the overlying unsaturated vadose zone, resulting in less sulfide oxidation-reduction increases in salinity or acidity of water. In fact, sulfide-reduction rather than oxidation may be the predominant process below the water table. Dockins et al. (1980) found substantial populations of sulfate-reducing Desulfovibrio desulfuricans bacteria in 25 of 26 groundwater samples (including spoil waters) from Southeastern Montana. Fluctuation of the water table may tend to increase dissolved solids concentrations in the saturated zone by alternating leaching and weathering processes in the overlying vadose zone as the water table rises and falls. As the water table lowers, weathering processes tend to increase in the dewatered zone; as it rises, leaching and transport of dissolved and soluble constituents may increase the dissolved solids concentrations in the saturated zone. Such changes in water level may correspond to discontinuous precipitation, snowmelt, soil freezing and thawing, and mine-related application of water to the surface.

During flow in the saturated zone, pollutant concentrations in groundwater may increase or decrease due to chemical, physical, biological and/or radioactive processes. The particular processes that occur depend on the respective conditions of the water solution and its environment. Typical processes that affect groundwater concentration in the saturated zone include adsorption, ion exchange, dissolution, chemical precipitation, oxidation-reduction, physical dispersion, dilution, various biological processes, radioactive decay, and evapotranspiration.

Monitoring Needs--

Two types of saturated zone monitoring can be done. One type can be done during pit dewatering adjacent to a specific area of spoils. In this case, pit water, water from wells tapping nearby coal seams and overburden, and monitor wells in the spoils can be sampled. The second type is for spoils beyond the influence of pit dewatering. In this case, monitoring pit discharge is unnecessary; however, monitoring is still necessary for groundwater in coal seams and overburden adjacent to the spoils.

Monitoring needs for the saturated zone include aquifer tests on saturated spoils, determination of the extent of saturated spoils, definition of groundwater flow direction in the spoils, and analysis of spoil groundwater quality, including trace elements, organic chemical constituents, and radiological parameters. All of these parameters are important in characterizing mining-related impacts to the groundwater system and verifying the suitability of the spoil aquifer for postmining uses. It is essential to consider the effects of mining on groundwater system hydraulics as well as water quality impacts.

In the Gillette, Wyoming study area, wells in the Wasatch Formation, coal seam, and underlying Fort Union Formation are needed in close proximity to the spoils to provide background water quality. Groundwater conditions in undisturbed materials adjacent to the spoils must be understood to interpret the results of monitoring groundwater in the spoils.

Monitoring and testing wells in spoils should be completed at diverse depths in the saturated zone, since basal spoils can be much more permeable. Monitoring spoil water quality in the most permeable zones will provide insight into possible off-site consequences of pollutant transport.

Alternative Monitoring Approaches--

Nonsampling methods--Collection of existing data to characterize the hydrogeology of the mine area is the major nonsampling method.

Sampling methods--The composite contribution of contaminants to the groundwater by mine spoils and other upgradient sources, including mine-related activities at the surface, may be measured by monitoring the saturated zone. In some instances, approximate identification of the relative contributions of several contributing water sources may be possible by comparing time and space distributions of the quantity and quality of water changes in the saturated zone with observable time and space variables of potential sources. Because of the hidden and complex nature of the spoils zone, the contribution of the spoils is likely to be less amenable to direct measurement than the contributions of other more observable sources at the surface. Under such conditions, estimating the contribution of other sources and the influx to the saturated zone in a water balance calculation may be feasible.

Monitoring and knowledge of the geologic framework and related groundwater hydrology will indicate the routing of groundwater flow and any entrained contaminants from the spoils zone into downstream areas. The aquifer characteristics for, and water levels in, the emplaced spoils need to be determined. Also, the site-specific geohydrologic framework for undisturbed materials adjacent to the spoils must be developed, including subsurface geology, water levels, aquifer characteristics, and groundwater quality. Much of this information can be gathered in the course of monitor well construction.

A number of new wells should be drilled in the spoils after emplacement. These can be constructed while pit dewatering is still occurring nearby. These wells should be 10-inch-diameter boreholes equipped with 6-inch-diameter PVC casing to allow proper pump tests. The casing would be perforated at the depth of expected eventual saturation when pit dewatering ceases. The wells should be packed opposite the perforations with gravel of known composition. The upper 10 to 20 feet of annulus around the well casing should be sealed. The wells should be properly developed upon completion to remove drilling mud or other foreign material. The top of the casing should extend several feet above the ground surface, have a locking cap, and be protected by barriers.

Wells in the spoils can be test pumped to determine aquifer characteristics once water levels have recovered from pit dewatering. Conducting tests with the maximum possible saturated thickness is advisable.

Interpreting the results of groundwater monitoring in saturated spoils requires additional groundwater monitoring in materials adjacent to the spoils. For example, in the Campbell County, Wyoming area, this would include Wasatch Formation overburden, coal, scoria, alluvium, and Fort Union Formation underburden, depending on the particular area. Existing monitor wells can indicate regional groundwater conditions in the coal seam overburden, but regional groundwater conditions are poorly known for alluvium and the Fort Union Formation beneath the coal. In the early stages of mining, pit discharge near emplaced spoils can be monitored, as well as additional wells in native materials adjacent to the spoils, particularly upgradient. This requires several monitoring wells in the coal seam, several additional monitoring wells in the overburden, and possibly additional wells in the alluvium and underburden.

Both solid and liquid samples should be collected from the saturated zone. Solid material should also be sampled during well drilling. Solids penetrated by the monitor well should be sampled to allow interpretation of the results of groundwater quality monitoring. Since some of the spoil materials are well consolidated, the optimal drilling method is uncertain, but drill cuttings could be collected in any case. Solids sampling data may be valuable for evaluating factors such as trace metal migration in groundwater. Additional holes should be periodically drilled into spoils near monitor wells to allow sampling and analysis of solids to correlate with the results of groundwater quality sampling.

When the optimal pumping duration for collecting representative water samples has been determined, samples should be collected monthly for the first year. These results can be used to determine the proper sampling frequency for the duration of the monitoring program. Climatic factors, such as precipitation events, should be considered in determining sample collection dates. Pumping tests in spoils should allow ample opportunity to collect samples for chemical analyses over several days or weeks.

Results may be available from existing pit discharge monitoring programs. Pit discharge is monitored at the point of discharge to surface for a few parameters. Weekly grab samples can be collected for 1 year and the frequency adjusted thereafter. Specific pollutant sources of pit discharge samples are difficult to interpret, however, unless a complete monitoring program exists for all [illegible] of pit recharge. At some mine sites, gravity discharge from the spoils zone might be monitored before mixing with other pit waters, simplifying interpretations.

Solids beneath the water table should be analyzed for determinations similar to those specified for spoils as discussed under Step 3, Identify Potential Pollutants.

For water, major inorganic chemical constituents should be determined in addition to pH, total dissolved solids (residue at 180°C), and electrical conductivity. Such determinations allow comparison of cation-anion sums, total dissolved solids versus electrical conductivity, and calculated total dissolved solids versus residue. Occasional samples should have total dissolved solids (ignition at 316°C) determined. Boron, fluoride, and various nitrogen forms should also be determined on occasion. An exhaustive suite of trace elements should be determined for at least one sample of water taken from each well near the end of the pump test. This will aid in selecting parameters to be routinely determined. Iron, manganese, arsenic, selenium, cadmium, chromium, lead, molybdenum, and vanadium, if pertinent, should be determined frequently. Also, the results of the pollutant-source sampling program should be used to choose trace elements of importance in groundwater quality monitoring.

Federal regulations specify that total suspended and dissolved solids, total iron, pH, and total manganese should be determined for groundwater. State regulations may require analyses for additional parameters.

The gross organic chemical composition of groundwater can be determined through analysis of dissolved organic carbon. More detailed determinations can be recommended if results obtained from the gross determinations indicate their desirability. Uranium and thorium content and gross alpha activity, gross beta activity, and radium-226 activity should be determined on several water samples from each well and the pit discharge early in the program.

Similar analyses should be made of water samples from monitor wells in undisturbed materials near the spoils. Water levels in spoils wells should be monitored at least monthly. Continuous water level recorders should be installed in key wells. Annual fluctuations and long-term trends of water levels may be critical for controlling spoil water quality.

Costs for Step 7 include labor for drilling supervision, sampling, and interpretation of results; operational costs for drilling, miscellaneous sampling equipment, and analyses of water and solid samples; and capital costs for wells, pumps, etc.

Recommendations--

The approach for monitoring pollutant mobility in the saturated zone should be custom designed for each mine site. An estimated 50 to 100 acres of spoils at each mine will be reclaimed each year. About six monitor wells should be constructed annually in the spoils. These wells will average 100 feet deep and be equipped with 6-inch-diameter PVC casing. Each well should be carefully surveyed to document location and land-surface elevation. Each of the wells installed during the first year should be pump-tested and water levels recorded. Approximately three water samples should be analyzed from each test. An average of three samples of solid materials penetrated by the monitor wells should be analyzed for each well. Samples of pit water can be obtained from the pit sump pump or, if possible, from representative spoil discharge before it mixes with other water in the pit.

Individual aquifers within and downgradient from the spoils should be monitored for pollution from the spoils zone and potential for affecting downstream water uses.

A monthly sampling and water level measurement frequency based upon average groundwater flow and discharge rates is initially recommended for monitor wells and pit discharge. If flow rates and sample parameter values vary widely, increased sampling may be required. A portable submersible pump, generator, tripod, winch, pump column, discharge line, and electric cable will be necessary. A two-technician team probably will be required; it should be able to sample several wells per day. Sampling of pit discharge will not require extra time.

Water from below the water table can be analyzed for the same constituents specified for solids under Step 3, Identify Potential Pollutants. Procedures for preservation of samples and chemical analyses are presented in Manual of Methods for Chemical Analysis of Water and Wastes (U.S. Environmental Protection Agency, 1974).

For water samples, the following should be determined routinely:

- Calcium
- Magnesium
- Sodium
- Potassium
- Carbonate
- Bicarbonate
- Sulfate
- Chloride
- Boron
- Fluoride
- Total nitrogen
- Silica
- Iron
- Manganese
- Arsenic
- Selenium

- Nitrate
- pH
- Total dissolved solids (residue at 180°C)
- Electrical conductivity
- Lead
- Cadmium
- Chromium
- Dissolved organic carbon.

Several samples collected early in the program, such as during the pump tests, should be analyzed for:

- Total dissolved solids (ignition at 316°C)
- Iodide
- Bromide
- Vanadium
- Nickel
- Copper
- Zinc
- Barium
- Molybdenum
- Silver
- Tungsten
- Antimony
- Titanium
- Rubidium
- Strontium
- Aluminum
- Cobalt
- Cesium
- Uranium
- Thorium
- Alpha activity
- Beta activity
- Radium-226 activity.

RECLAMATION AIDS

Step 3. Identify Potential Pollutants

Fertilizer sources most likely to affect the quality of water within reclaimed areas include the major mineral nutrients nitrogen and phosphorus and certain micronutrients, if applied in relatively large amounts. Ammonium-nitrate is entirely soluble in water when used as a fertilizer. Nitrate-nitrogen (NO_3^-) is immediately available to plants, as this is the form that plants primarily absorb, though some plants have the ability to absorb small amounts of ammonia-nitrogen (NH_4^+) by direct cation exchange.

Because ammonia- and nitrate-nitrogen have the ability to move up and down in the soil solution, both should be included in the monitoring effort. The cationic nature of ammonia-nitrogen permits its absorption and retention by soil colloidal material if the cation exchange capacity of the soil is sufficiently high; otherwise, it will be removed in percolating water. Nitrate is highly subject to leaching as it is completely mobile in soils. Hence, its inclusion in the monitoring effort is highly justified.

Because the phosphate ion is almost immobile in soil, phosphorus moves very slowly from the point of placement. Also, the activity of phosphorus is lower in alkaline or calcareous soils due to the high calcium cation (Ca^{+2}) activity, a large amount of finely divided calcium carbonate, and a large amount of calcium-saturated clay, all of which contribute to the precipitation of phosphate on solid phase calcium carbonate. Therefore, phosphorus is a doubtful source of groundwater contamination and need not be included in the monitoring effort.

Monitoring Needs--

Nutrients being applied to reclaimed areas must be identified and quantified.

Alternative Monitoring Approaches--

Pollutant-specific information on monitoring activities by a coal company on fertilizer application to reclaimed areas should be collected. For example, any existing water quality data should be requested together with information on fertilizer application. Alternatively, the fertilizer application areas and its rate should be clearly delineated.

Water samples for characterizing pollutants associated with fertilizer application should be obtained from surface waters adjacent to reclaimed areas. Samples should be collected before and after fertilization, with any increases in the concentration of particular constituents being noted.

These alternative methods are possible for analyzing surface water samples. First, all samples may be submitted for complete analyses including the major inorganics (nitrate-nitrogen, ammonia-nitrogen, calcium, magnesium, sodium, potassium, bicarbonate, chloride, sulfate, phosphate, silica, total nitrogen, pH, and electrical conductivity) and trace constituents (iron, manganese, zinc, copper, cadmium, chromium, arsenic, molybdenum, vanadium, and selenium).

A second technique is to completely analyze the first few water samples collected during the program. Subsequently, analysis for known fertilizer constituents should be continued, while those not applied as fertilizer could be excluded.

Selecting a sampling frequency to characterize the waterborne pollutants in a source, such as applied fertilizer, is generally a trial-and-error process. One method is to sample every few days or weekly until time trends in the quality of the source are characterized. Subsequent samples can be obtained by sampling weekly, monthly, or quarterly. An increase in sampling frequency may be warranted by unusual circumstances. For example, a spill of fertilizer on the watershed area draining into surface water might justify an increase in sampling frequency.

Costs for Step 3 include labor for data collection and sampling, operational costs for analyses, and capital costs for miscellaneous sampling equipment.

Recommendations--

All areas receiving fertilizer should be delineated, along with the nature of the application and its rate. Surface water in the area should be sampled before and after fertilization to characterize water quality and quantity trends. Initial water samples should be analyzed completely, with later sample analyses only for those constituents present in the fertilizer.

Step 5. Evaluate Infiltration Potential

The purpose of determining the infiltration potential of a source is to quantify the volume of water and associated pollutants moving to the underlying saturated zone.

The priority ranking report (Everett, 1979) indicates that the soil material used for surface dressing is expected to have a higher infiltration than the spoil material but lower, after settlement, than the structured natural soils.

Monitoring Needs--

The primary monitoring need is the quantity of water that infiltrates the fertilized reclaimed soil.

Alternative Monitoring Approaches--

Infiltration capacity can be determined by laboratory tests of spoil permeability, ring infiltrometers, or sprinkler-type infiltrometers. These techniques are discussed in the monitoring design for infiltration capacity of spoils.

Costs for Step 5 include labor for infiltration measurements and data collection and capital costs for ring infiltrometers. These costs will be similar to those for spoils (Step 5, Evaluate Infiltration Potential).

Recommendations--

Infiltration capacity can be determined using a single-ring infiltrometer. Site selection should be based on information collected during identification of potential pollutants for spoils.

Step 6. Mobility in the Vadose Zone

The general purpose of this step is to estimate or measure the movement of pollutants in the vadose zone underlying a source or sources. Pollutants associated with fertilizers will be specified upon implementation of Step 3, Identify Potential Pollutants. Similarly, the potential for pollutants to move into the vadose zone from the point of application will be determined during Step 5, Evaluate Infiltration Potential.

Because ammonium-nitrate is completely soluble if sufficient moisture exists to solubilize it, the two types of nitrogen salt that compose this fertilizer have the ability to move up and down in the soil solution. Tisdale and Nelson (1975) discuss the retention of nitrate-nitrogen in soil.

Nitrified ammonia is subject to leaching. Nitrate-nitrogen is completely mobile in soils and, within limits, moves largely with the soil water. Under conditions of excessive rain, it is leached out of the upper horizons of the soil. During extremely dry weather, upward capillary movement of water is possible. Under such conditions, nitrates will accumulate in the upper horizons of the soil or even on the soil surface.

Figure 4-3 illustrates the pattern of nitrate distribution in some soil columns that differ in their particle-size distribution. The percentage of large pore space and the amount of coarse sand decrease from sample A to sample H, although the total pore space is relatively constant (Tisdale and Nelson, 1975).

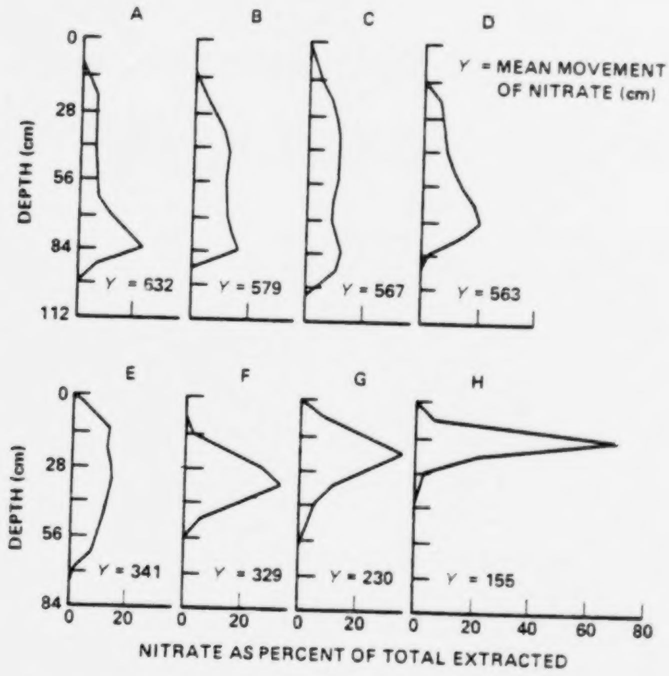

Figure 4-3. Distribution of nitrates through columns of coarse-textured soils after adding 3.29 cm of water (after Tisdale and Nelson, 1975).

Monitoring Needs--

Data gaps exist in knowledge of the factors tending to attenuate pollutants within the vadose zone (i.e., dilution, filtration, sorption, chemical precipitation, buffering, oxidation-reduction, volatilization, and biological degradation and assimilation) and field data on transformations in waterborne pollutants during flow in the vadose zone.

Alternative Monitoring Approaches--

The potential attenuation of pollutants in the vadose zone can be depicted by constructing a matrix comprising attenuating factors (rows) versus specific pollutants (columns). Each location in the matrix should specify the relative potential of a factor (e.g., sorption) to attenuate a specific pollutant (e.g., ammonia-nitrogen). Each position in the table may be filled in by subjective evaluation or on the basis of actual measurement. Subjective evaluation involves examining available data and estimating the effect on the mobility of a specific pollutant. Some actual attenuating factor values may be obtainable from field measurements. For example, spoil sample analyses in a previous step may yield analytical data on pollutant mobility. A second method is to use previously installed instruments to determine water and pollutant movement in the vadose zone, such as neutron moisture logging access wells and tensiometers.

Field activities can be initiated to monitor the actual movement of pollutants in the vadose zone. Methods include collecting drill or auger samples for laboratory analysis and installing suction-cup samplers. Collection of samples of vadose zone sediments will entail using hand or power augers or core samplers, depending on physical composition and depth of the underlying spoil.

Suction-cup samplers can be installed within the fertilized areas at depths corresponding to tensiometer locations. Collection bottles and the vacuum supply should be located in buried shelters, with vacuum and discharge lines from the suction-cup and tensiometer units protected by conduits. During sampling, vacuum equivalent to water-content pressure in tensiometers is applied to the suction cups.

Water samples collected from suction cups can be analyzed completely or partially. A complete analysis includes the major inorganics and trace constituents listed under Step 3, Identify Potential Pollutants. Upon examination of the results of a complete analysis, subsequent samples may be analyzed only for those constituents found in greater-than-permissible concentrations and for those present in applied fertilizer.

Solid samples can be used to obtain saturated extracts via techniques in Methods of Soil Analysis (Black, 1965).

Sampling frequency with suction-cup samplers depends on the water pressure within the surrounding porous matrix. If the system is very dry, water will enter the cups very slowly. A week or more may be required to collect a sufficient sample for analysis. In the extreme case, the cups become inoperable when water pressure is less than -0.8 atmosphere, and samples may become available only once or twice a year. Sampling frequency cannot be explicitly defined until field units are installed and operating. For a wet system, it may be desirable to collect weekly samples until quality trends are established. Later, samples might be obtained monthly.

Solid sample collection schedules can be adjusted as appropriate after initial testing to establish quality levels and trends.

Costs for Step 6 include labor for constructing an attenuation factor versus pollutant matrix and interpreting results, installing suction-cup samplers, and collecting liquid and solid samples; operational costs for analyses; and capital costs for suction-cup samplers.

Recommendations--

The monitoring program should include construction of a matrix of attenuating factors versus specific pollutants using available data when possible, supplemented with intuition. Water movement in the vadose zone underlying fertilized areas should be determined using facilities developed during previous steps. A few suction cups should be installed at depths corresponding to tensiometer locations, with sample analysis frequency dependent on soil moisture conditions. Suction cups should be sampled whenever possible during very dry conditions. For wet conditions, suction cups can be sampled more frequently until quality trends are established. Thereafter, samples can be analyzed monthly.

Step 7. Mobility in the Saturated Zone

The purpose of this step is to estimate or measure the attenuation of source pollutants during flow in the zone of saturation. The pollutants of concern will be those that have not been completely attenuated during flow through the vadose zone. As pointed out by Todd et al. (1976), the principal processes involved pollutant attenuation in the saturated zone include physical-chemical reactions or dilution. For pollutants in a source such as fertilizer, physical-chemical processes are sorption, precipitation, volatilization, and oxidation-reduction reactions. Dilution is affected by hydrodynamic dispersion resulting from such effects as convection, diffusion, and flow tortuosity.

Monitoring Needs--

Information gaps currently exist in predicting the effect of physical-chemical reactions and dilution on pollutant mobility within aquifers underlying fertilized areas.

Alternative Monitoring Approaches--

The relative effect of various physical-chemical mechanisms for attenuating pollutants within the saturated zone can be estimated by constructing a matrix similar to that for the vadose zone; i.e., a table consisting of attenuating mechanisms (rows) versus pollutants (columns). Attenuating mechanisms consist of physical-chemical factors (i.e., sorption, precipitation, volatilization, pH, oxidation-reduction [Eh], and decay) and dilution. When completed, the table will show, in a mixed qualitative-quantitative sense, the pollutants that should be monitored.

Completion of the matrix for the physical-chemical items requires specific information on exchange capacity of aquifer materials and the Eh and pH of groundwater, as well as on the specific pollutants entering the saturated zone. Many of the physical-chemical parameters can be quantified from analyses of drill cuttings obtained during well construction and from field analyses of Eh and pH. Identification of pollutants must await results of mobility studies in the vadose zone.

Groundwater samples can be obtained for analysis and ensuing data examined to characterize pollutant attenuation. Data from existing wells and wells installed during previous monitoring steps can be used in the matrix. In actuality, a special sampling program should not be required because samples should be available from these steps.

Recommendations--

The recommended approach includes all of the methods discussed above. Costs for Step 7 include only labor for construction of the attenuation mechanism versus pollutant matrix.

SECTION 5

MONITORING RECOMMENDATIONS FOR MISCELLANEOUS SOURCES OF POLLUTION

Steps 3, 5, 6, and 7 of the groundwater monitoring methodology have been developed for miscellaneous sources of potential pollution related to surface coal mining activities. These sources include spills and leaks, solid wastes for road construction, liquid shop wastes, explosives, and mine sanitary and solid wastes. Step 8 has been developed for specific mines and is presented in Everett (1979).

SPILLS AND LEAKS

Step 3. Identify Potential Pollutants

Mining operations require the movement and storage of a large number of substances that can be spilled or leaked from their containers. Gasoline, diesel fuel, oils, and lubricants are used in the shop area. Ammonium-nitrate and fuel oil (ANFO) are used for blasting. Herbicides are used to clear rights-of-way, and pesticides, fertilizers, and soil amendments are used in reclamation. Topsoil, overburden, parting materials, and coaly waste are transported to stockpiles and, of course, coal is transported from the mine pit to storage facilities.

Monitoring Needs--

Monitoring needs include characterizing the types of substances transported and stored on the lease area and their quantities. The current extent of monitoring for spills and leaks at active mines is unknown.

Alternative Monitoring Approaches--

Nonsampling methods--Substances transported and stored at the mine can be determined through discussions with mine personnel and field observation. Storage locations and transportation routes can be checked for evidence of spills or leaks. Accident records or past spills can be reviewed for potential problem areas that should be watched more closely.

The costs include:

- Labor costs: interviews with mine personnel to determine quantities and transportation requirements or substances stored on the lease area, review of accident reports and records of previous spills or leaks, and field checking storage locations and transportation routes for potential pollutants resulting from spills or leaks.

- Operational costs: field transportation.

Sampling methods--Substances for which analyses do not exist can be sampled and analyzed. Grab samples can be taken if field monitoring personnel are present at a spill or discover a leak.

The costs include:

- Labor costs: discussions with mine personnel and field observation, review of existing records and analyses, and sampling substances for which analyses are not available.

- Operational costs: analysis, sample bottles, etc., and field transportation.

Recommended Monitoring Approach--

Nonsampling methods are recommended for monitoring spills and leaks.

Step 5. Evaluate Infiltration Potential

Infiltration potential depends greatly upon the location of leaks or spills. Although certain areas may be identified as susceptible to a large number of leaks or spills, in most cases it is not cost-effective to try to characterize the infiltration potential of ground materials in local areas because of the possibility of a spill.

Monitoring Needs--

The following needs are associated with monitoring infiltration potential: storage locations, areas where spills are likely to occur, procedures for checking tanks and pipelines for leaks, and emergency procedures.

Alternative Monitoring Approaches--

The following nonsampling monitoring methods are available:

- Obtain information from field observations and discussions with mine personnel on storage locations and areas where spills may occur

- Review records of past spills for information on likely spill areas

- Check tanks and pipelines periodically for leaks using a dipstick or pressure-sensitive devices and visually check aboveground facilities for signs of leaks

- Review emergency cleanup procedures and check for preparedness of employees and equipment.

Costs for this include:

- Labor costs: field observations and discussions with mine personnel, review of past records, checking tanks and pipelines for leaks, and review of emergency procedures.

- Operational costs: field transportation.

- Capital costs: possibly, dipsticks or other devices for checking tanks and pipelines for leaks.

Recommendation--

The nonsampling approach is preferred for determining the infiltration potential of spills and leaks.

Step 6. Evaluate Pollutant Mobility in the Vadose Zone

Because of the wide range of locations at which spills and leaks might occur, vadose zone monitoring is not recommended.

Step 7. Evaluate Pollutant Mobility in the Saturated Zone

Monitoring the saturated zone is not recommended unless a particularly bad spill or leak occurs.

SOLID WASTES FOR ROAD CONSTRUCTION

Access and haul roads are constructed on a variety of surfaces, including coal, unmined ground, and reclaimed spoils. Roadbeds are often constructed of overburden and most roads are surfaced with scoria. Pit water is continuously applied to some roads to reduce dust. Dust suppressants such as calcium chloride and lignin sulfonate are also sprayed on roads, particularly at mines where water supplies are limited. The extent to which roads mav constitute a pollution source depends upon construction materials, the quality and quantity of water or dust suppressant used, and the total land area covered by roads.

Step 3. Identify Potential Pollutants

Potential pollutants from road construction include:

- Major and trace inorganics leached from road construction overburden materials

- Major and trace inorganics from pit discharge water applied to the roads for dust suppression

- Major inorganics from calcium-based dust suppressants

- Organics due to application of other dust suppressants such as Coherex, a cold water emulsion of petroleum resins mixed with water and applied to the roads.

Major inorganics include calcium, magnesium, potassium, sodium, chlorine, carbonates, nitrates, sulfates, hydrogen sulfide, silica, etc. Trace inorganics include iron, manganese, zinc, copper, cadmium, chromium, arsenic, lead, molybdenum, vanadium, uranium, thorium, ruthenium, and selenium.

Alternative Monitoring Approaches--

Nonsampling methods--Potential pollutants are a function of the materials used to construct the roads. Information on roadbed materials can be obtained by:

- Discussions with mine personnel
- Review of road construction records
- Field observation
- Review of geophysical logs of overburden materials
- Requesting a complete analysis of commercially available calcium or organic-based dust suppressants.

Any costs incurred for these activities are minimal and only represent the time necessary to obtain the information.

Sampling methods--When roads are heavily watered for dust control, pit water quality partially determines potential pollutants due to road construction. Pit discharge can be sampled and analyzed.

An alternative method for determining potential pollutants is to install a series of monitoring wells perpendicular to the road. Samples from these wells can be analyzed and compared to determine if any contaminants are associated with the roadbed. Wells can be completed in the saturated zone or suction-cup samplers can be installed for sampling in the vadose zone. Both the wells and samplers can be used for monitoring later stages of the program, such as groundwater quality, mobility in the vadose zone, and attenuation in the saturated zone.

Any existing wells near access and haul roads can be sampled individually or incorporated into a series of sampler wells. A well series can be installed in one localized area along a road, or several such areas can be chosen to represent different roadbed materials, construction practices, and local geohydrology.

Pit discharge and monitoring well samples should be analyzed to determine pollutants initially present. Complete monthly analyses can then be run to determine the presence of new pollutants in the system. This frequency may be altered as initial results indicate. Discussions with mine personnel regarding road construction should also be held monthly.

A complete analysis for major inorganics, trace constituents, organics, and microorganisms should be performed. Followup analyses can be made to coincide with analyses required for other sections of the overall monitoring program.

The costs include:

- Labor costs: inventory of roadbed materials, review of overburden geophysical logs, sampling of pit discharge, and installation and sampling of monitoring wells and lysimeters.
- Capital costs: samplers, monitoring wells, and suction-cup lysimeters.
- Operational costs: water quality analysis, sample bottles, and operation and maintenance expenses.

Step 5. Evaluate Infiltration Potential

Potential pollutants must infiltrate the roadbed or ditches and the ground surface beneath to reach the vadose zone. Infiltration potential depends very heavily on:

- Roadbed materials and construction practices
- Types of underlying materials
- Amount of water coming in contact with the road surface.

Monitoring Needs--

Assuming existing monitoring of infiltration parameters is unknown, the following items are monitoring needs:

- Water balance, including precipitation, evaporation, and amount of water applied to the roads for dust control
- Total road area
- Types of surface materials
- Permeability of roadbed materials
- Types of underlying materials
- Presence of streams and ponds near roads, including seasonal flows
- Direction and character of ditch flow along or under roads.

Alternative Monitoring Approaches--

Nonsampling methods--Water balance information can be obtained from rain gauges and evaporation pans at the site, from weather data, or possibly from mine personnel. Truckloads of water applied to the roads can be counted as described in Step 4, Identify Groundwater Usage. The amount of chemical dust suppressants used and methods of application can be obtained by discussions with mine personnel or estimated from mine maps and road specifications. The type and infiltration potential of road surface or ditch materials can be determined through field observations, discussions with mine personnel, and/or leaching studies on similar materials.

Similarly, roadbed materials can be characterized by discussions with mine personnel, review of overburden geophysical logs, and/or leaching studies of similar materials. Information on underlying materials can be obtained from discussions with mine personnel and/or leaching studies. Soil infiltration data may be available from the Soil Conservation Service. Locations of streams and ponds can be determined by discussions with mine personnel and field observation.

Costs involved in nonsampling methods of monitoring are primarily for labor. They include:

- Obtaining precipitation and evaporation data
- Counting truckloads of water applied to roads
- Discussions with mine personnel regarding road area and construction material and underlying materials
- Leaching studies
- Locating streams and ponds.

Capital costs may include some leaching studies.

Recommendations--

If potential pollutants are identified, infiltration rates should be estimated.

Step 6. Evaluate Pollutant Mobility in Vadose Zone

Monitoring Needs--

The objectives of monitoring in the vadose zone are to determine the following:

- Direction and velocity of water movement
- Presence of perched layers
- Movement of pollutants.

Alternative Monitoring Approaches--

Nonsampling methods--Nonsampling methods include neutron moisture logging in access wells and installation and operation of tensiometers and moisture blocks. Moisture logging and tensiometer data can be used to determine flux. Moisture logging can also be used to identify perched layers.

Sampling methods--Several sampling methods can be used to monitor the movement of pollutants through the vadose zone. Split-spoon samples of vadose zone sediments can be analyzed in the laboratory for organics. Even though the cost of obtaining samples with split-spoon samplers is more expensive than with augers, the method is often preferred because of the better accuracy gained in estimating the vertical position of the sample. Samples from suction-cup lysimeters can be analyzed periodically for changes.

Lysimeters and perched water table wells should be sampled weekly, or as frequently as possible, until quality trends are established. Monthly samples can then be taken. Sediment should be sampled monthly until a trend is established, then sampled every 6 months.

Initially, all samples should be analyzed completely for major inorganics, trace constituents, and organics. Subsequent analyses can include only major inorganics and trace constituents and organics that have been found in excessive concentrations.

The costs include:

- Labor costs: neutron moisture logging, installation and operation of tensiometers and moisture blocks, collection of sediment samples, and sampling wells and lysimeters.
- Capital costs: neutron moisture logger, tensiometers, moisture blocks, and auger.
- Operational costs: sediment analysis, water quality analysis, and sample bottles, etc.

Recommendations--

Nothing should be done unless pollutants are indicated and a high infiltration potential is found.

Step 7. Evaluate Pollutant Mobility in Saturated Zone

Monitoring Needs--

Source-specific monitoring of mobility and attenuation is necessary to collect information on:

- Aquifer characteristics
- Direction and velocity of water movement

- Direction and velocity of pollutant movement.

Recommendations--

Nothing should be done unless pollutants are indicated and a high infiltration potential is found.

LIQUID SHOP WASTES

Liquid shop wastes include fluids such as oils and lubricants, which are used in the repair and maintenance of mining equipment, and detergents and wash water used for cleaning trucks and machinery. Waste oils are probably stored either for recycling or disposal away from the shop area. Other waste products and water may enter some type of a sewer system. Oil/water separators are usually employed. Water from equipment washing will probably run onto the ground in a designated equipment washing area.

Step 3. Identify Potential Pollutants

Potential pollutants include oils, lubricants, gasoline, wash water, and detergents, or other substances that may be mixed with these fluids.

Monitoring Needs--

Current monitoring for pollutants in the shop area at coal strip mines is unknown. The following information gaps exist: types and quantities of liquid wastes, quantity of wash water used, location of washing areas, and use of detergents, etc. in wash water.

Alternative Monitoring Approaches--

Nonsampling methods--Several nonsampling methods for identifying potential pollutants include discussions with mine personnel on types and quantities of liquid wastes produced, quantity of wash water used, location of washing areas, use of detergents, etc. All of the above can be confirmed through field observation. Quantities of liquid wastes and wash water used can be measured and wastes can be inventoried regularly.

Sampling methods--Several sampling methods exist for identifying potential pollutants. The wastes themselves can be sampled and analyzed completely. Lysimeters can be installed in the vadose zone beneath the shop area and sampled for potential pollutants. Wells can be installed in perched layers and sampled. Piezometer clusters can be installed for sampling from the saturated zone.

Samples should be taken on a weekly basis until potential pollutants have been identified. Subsequent samples can be taken once a month or as necessary to identify any new contaminants entering the system.

All initial samples should be analyzed completely for major inorganics, trace constituents, organics, and microorganisms until potential pollutants have been identified.

Costs include:

- Labor costs: discussions with mine personnel, field observation of liquid waste disposal practices, measurement of liquid waste quantities, inventory of wastes, sampling of liquid wastes, and installation and sampling of lysimeters, perched water table wells, and piezometer clusters.
- Capital costs: lysimeters, water table wells, and piezometer clusters.
- Operational costs: water quality analysis and sample bottles, etc.

Recommendations--

Use of all the monitoring approaches in the foregoing categories is the overall preferred monitoring approach for identification of potential pollutants due to liquid shop wastes.

Step 5. Evaluate Infiltration Potential

The infiltration potential of liquid shop wastes depends in large part on how these wastes are disposed of or stored. Oils, for example, if carefully stored for recycling will have a much lower probability of reaching the subsurface than wash water poured onto the ground.

Monitoring Needs--

Information should be obtained on:

- Storage and disposal methods of liquid wastes
- Amount of maintenance and equipment washing done outdoors
- Type of surface materials in shop area.

Alternative Monitoring Approaches--

Nonsampling methods--Monitoring methods include:

- Obtaining information on storage and disposal methods through discussions with mine personnel and field observation
- Checking storage tanks and shop area for evidence of spills and/or leaks
- Determining infiltration of ground surface by conducting leaching studies of similar materials.

Costs include:

- Labor costs: discussions with mine personnel and field observation, checks for spills or leaks, and leaching studies.

- Capital costs: leaching studies.

Step 6. Evaluate Pollutant Mobility in Vadose Zone

Monitoring needs are to obtain information on:

- Direction and velocity of water movement in the vadose zone

- Presence of perched layers

- Movement of pollutants.

Step 7. Evaluate Pollutant Mobility in Saturated Zone

Monitoring needs are to obtain information on:

- Aquifer characteristics

- Direction and velocity of water movement

- Direction and velocity of pollutant movement.

EXPLOSIVES

At mining sites with well-consolidated overburden and coal seams, explosives are used to dislodge the materials before their removal. The principal explosive used is an ammonium nitrate-fuel oil mixture known as ANFO. The water pollution potential of explosives used for surface coal mining has not been studied in detail in the West. In an incomplete explosion, some ammonium-nitrate and fuel oil residual will occur. Also, spillage of explosives can create a pollution potential. Such materials could directly affect the quality of pit water. Stockpile and spoils may also contain these materials and affect groundwater quality.

Step 3. Identify Potential Pollutants

The primary potential pollutants from explosives appear to be ammonia-nitrogen, nitrate-nitrogen, fuel oil, and possibly trace organics.

Monitoring Needs--

Records are kept of blasting operations at western coal strip mines. No direct monitoring of explosives in relation to water pollution potential, however, is assumed to be performed. Determination of the approximate amounts of residual ammonium-nitrate and fuel oil from explosives is needed. Spills of these materials should also be monitored.

Alternative Monitoring Approaches--

Nonsampling methods--Much of the required information for nonsampling monitoring is available because of provisions of the Surface Mining and Control and Reclamation Act and State Regulatory Programs. Specifically, locations, dates, and times of blasting, types of material blasted, number of holes and spacing, depth and diameter of holes, and type and weight of explosives used are recorded. From this information, maps can be prepared illustrating patterns in the use of explosives, such as hole density or tonnage of explosives. Records should also be maintained on location, amounts of spills of explosives, and cleanup measures.

Sampling methods--Both overburden and coal should be sampled before and after blasting and before removal from the pit. Although the blasted materials are eventually removed from the area, water may contact the materials and drain into the pit before their removal. Also, after the overburden is removed and before blasting the coal, the uppermost layers of coal should be sampled for explosives or residual materials. After the coal is removed, the uppermost layers of underburden should be sampled for explosives or residual materials. Water may run over both of these surfaces and pick up potential pollutants.

Because explosives may be used near the pit water body, sampling water in the pit and its disposal tributaries is recommended. In general, the direction of groundwater movement in the coal and overburden in areas where explosives are used will be toward the pit water body. Water could pick up residuals from explosives or spilled materials during flow over the surface of the pit. Based on present data, this is the most likely mechanism for pollutants from explosives to enter the pit water. Thus, the optimal situation is to monitor the amount and type of explosives and pit water at the same mine, a procedure followed in this monitoring program design. Water flowing across the pit a significant distance before entering the pit water body can be sampled along the flow path, as recommended in Section 3. At the same time, samples of solid materials beneath the flowing water can be sampled for residuals or spilled explosives. If any pollutant transport by groundwater is occurring, the recommended monitoring for groundwater seepage for pit water will detect it (see Pit Water, Steps 5, 6, and 7).

Samples of overburden and coal should initially be collected weekly for determination of explosives and residuals. When water is running over the surface of the pit and into the pit water body, monthly traverses should be made along the flow path. Both the water and the underlying materials should be sampled. The nitrogen forms and fuel oil residuals from ANFO, however, should be determined at least weekly.

Analyses for explosives and residuals can apparently be limited to the nitrogen forms, fuel oil, and possibly total organic carbon. Future studies, however, may detect pollutants unknown earlier but formed as residuals. If the inventory of type of explosive indicates additional potential pollutants, then they would also be determined in the water analyses. Saturation extract can be used for chemical determination of solid materials.

The costs involved will be related to the following considerations: man-hours required to review data collected in accordance with the Surface Mining Control and Reclamation Act and State Regulatory Programs; man-hours required to sample the overburden, coal pit water, and explosives throughout the mining operations; man-hours required to review the analyses of the explosives; and the chemical determinations from the solid material saturation extracts.

MINE SANITARY AND SOLID WASTES

Three methods of disposal are commonly used for sanitary wastes generated at the mine. They are:

- Septic tank and leach field systems
- Oxidation ponds and lagoons
- Package sewage treatment plants.

In addition, the sludge accumulation from the package sewage treatment plants must be disposed of.

Solid waste disposal techniques may involve:

- On-site landfill
- Off-site disposal facility
- Incorporation in mine spoils
- Incineration followed by land disposal of residue.

The monitoring recommendations for mine sanitary and solid wastes are adequately presented in Everett and Hoylman (1980). At most coal strip mines, these sources of pollution are minor and require minimal monitoring programs.

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APPENDIX A

CONVERSION FACTORS
U.S. Customary to SI (Metric)

U.S. customary unit			SI	
Name	Abbreviation	Multiplier	Symbol	Name
acre	acre	0.405	ha	hectare
acre-foot	acre-ft	1,234	m^3	cubic metre
cubic foot	ft^3	28.32 0.0283	l m^3	litre cubic metre
cubic feet per second	ft^3/s	28.32	l/s	litres per second
degrees Fahrenheit	°F	0.555(°F-32)	°C	degrees Celsius
feet per second	ft/s	0.305	m/s	metres per second
foot (feet)	ft	0.305	m	metre(s)
gallon(s)	gal	3.785	l	litre(s)
gallons per acre per day	gal/acre·d	9.353	l/ha·d	litres per hectare per day
gallons per day	gal/d	4.381 x 10^{-5}	l/s	litres per second
gallons per minute	gal/min	0.0631	l/s	litres per second
horsepower	hp	0.746	kW	kilowatt
inch(es)	in.	2.54	cm	centimetre(s)
inches per hour	in./hr	2.54	cm/h	centimetres per hour
mile	mi	1.609	km	kilometre

(continued)

CONVERSION FACTORS (continued)

U.S. customary unit			SI	
Name	Abbreviation	Multiplier	Symbol	Name
miles per hour	mi/h	0.45	m/s	metres per second
million gallons	Mgal	3.785	Ml	megalitres (litres x 10^6)
		3,785	m^3	cubic metres
million gallons per acre	Mgal/acre	8,353	m^3/ha	cubic metres per hectare
million gallons per day	Mgal/d	43.8	l/s	litres per second
		0.044	m^3/s	cubic metres per second
parts per million	ppm	1	mg/l	milligrams per litre
pound(s)	lb	0.454 453.6	kg g	kilogram(s) gram(s)
pounds per acre per day	lb/acre·d	1.12	kg/ha·d	kilograms per hectare per day
pounds per square inch	lb/in.^{2}	0.069	kg/cm^2	kilograms per square centimetre
		0.69	N/cm^2	Newtons per square centimetre
square foot	ft^2	0.0929	m^2	square metre
square inch	in.^{2}	6.452	cm^2	square centimetre
square mile	mi^2	2.590 259	km^2 ha	square kilometre hectare

APPENDIX B

ACID-NEUTRALIZATION CALCULATIONS FOR SPOILS

SULFUR DETERMINATION

Among the various chemical analyses to which overburden and minesoil samples have been subjected, pyritic sulfur content is most important when considering toxicity or potential toxicity from acidity. Pyritic sulfur content, knowledge of which allows calculation of the maximum amount of acid that might be produced during the weathering of a rock, is estimated from the total sulfur content after the sample has been leached to remove sulfates. The LECO Induction Furnace with Automatic Sulfur Titrator is used for the sulfur analyses (Beaton, Burns, and Platon, 1968; West Virginia University, 1971a). The step-by-step procedure used in the instrument operation follows.

Simplified procedure for determination of total sulphur using the LECO model 521-400 Induction Furnace with Variable Temperature Control Transformer and Timer and model 532-000 Automatic Sulfur Titrator

General Considerations -

a. For coal or very high carbon shale samples, sandwich sample (0.100 gram) between two scoops of MgO to prevent splashing of sample. A longer time of running may be expected with such samples.

b. Some samples, e.g., coal, when first placed in the furnace may change the color of the solution in the titration vessel to pink or purple (probably from organic matter being driven off the sample).

Some samples may contain halogens (I, Cl, F), which darken the solution in the titration vessel and will therefore produce S results that are low. This problem, if encountered, may be eliminated by the use of antimony in a trap between the furnace and titration assembly.

c. Generally, with low chroma samples (shale) or other types where high sulfur content might be present, either 0.2500- or 0.1000-gram samples should be run first. If sulfur is not detectable or more accurate values are desired in this sample weight, increase sample size to 0.5000 gram and rerun.

Sample Preparation -

a. Place one 0.2 ml scoop, level full, of iron chips in crucible, then

b. Weigh exactly 0.500 gram of 60 mesh sample into the crucible. (For samples such as shale and coal that contain or are suspected to contain over 1% sulfur, use only 0.100 gram.)

c. Add 1 scoop of MgO, about 0.5 mm^3.

d. Add 2 scoops of Fe powder and one Cu ring.

e. After adding each component, gently shake the crucible to evenly cover the bottom.

f. Place porous cover on the crucible (cover may be turned over and reused).

Solution Preparation -

a. Potassium iodate titrant:
   (1) 1.110 grams KIO_3/l, multiply buret reading by 5 (0.5-gram sample; 0.005 - 1.00 % S range)
   (2) 0.0444 gram KIO_3/l, multiply buret reading by 0.200 (0.5-gram sample; 0.0002 - 0.040 % S range).

b. Hydrochloric acid solution: 15 ml concentrated HCl/l H_2O.

c. Starch solution: Use only arrowroot starch. Add 2 grams of Arrowroot starch to 50 ml H_2O; stir well. Separately boil 150 ml H_2O and to this slowly add the 2-gram starch solution, stirring constantly. Cool and add 6 grams of potassium iodate to the solution; pour this solution into the polyethylene starch dispenser. Do not use starch over 5 days old.

Instrument Operation -

a. Read entire manuals on both LECO Induction Furnace and Automatic Titrator.

b. Turn ON "Filament Voltage"; grid tap to high position.

c. Turn on titrator--upper left switch (above "Endpoint Adjust")

d. Set timer switch to ON, adjust timer to 8 minutes, or a time sufficient to satisfy instructions p. and q.

e. Set "Titrate-Endpoint" switch to its middle position.

f. Slosh carboys containing HCl and KIO_3 to mix the condensate on the unfilled walls of the container.

g. Fill iodate buret.

h. Fill titrating chamber to mark; add one measure of Starch; bottom of meniscus shall be 2 3/8" below top of chamber.

i. Turn on oxygen; set pressure to 15 psi, flow rate to 1.0 liter per minute.

j. Turn "high voltage" ON.

k. Place sample crucible on pedestal, making sure it is centered; carefully raise sample fully and close switching level. Make sure sample platform makes airtight contact when closed, as evidenced by vigorous bubbling in top of titration cell.

l. Turn switch to "Endpoint".

m. After a few seconds when titrant level has stopped falling and titrating chamber is a deep blue color, refill buret or note and record initial buret reading; turn switch to "Titrate" (see instruction x. also).

n. Push RED button on timer to start analysis.

o. While a sample is being titrated, add the final quantities of iron and tin and copper to the next crucible.

p. Plate current must go to 300-350 mA for at least 15 seconds during the analysis; if not, rerun sample.

q. Adjust to prevent Plate Current from exceeding 350 mA.

r. When buret does not change reading for 2 minutes, and Plate Current has achieved 300 to 350 mA, it can be assumed that all of the sulfur has been driven from the sample. If buret is still changing when timer shuts off instrument, set Timer Switch to OFF, which restarts furnace, leave furnace on until buret is stable for 2 minutes, then turn Timer Switch to ON.

s. Set "Titrate-Endpoint" to middle position (IMPORTANT).

t. Lower sample platform, remove crucible using tongs, place fresh sample crucible in place, but do not close sample chamber.

u. Drain titrating chamber and refill every third sample, or more if a large quantity of titrant was used by the previous sample. Slightly drain titrating chamber to maintain original level.

v. Refill KIO_3 buret.

w. Close sample chamber, making sure it is tight.

x. Switch to "Titrate", or, if it is known that sample will evolve SO_2 slowly, leave switch at Endpoint - this acts as a "Fine" control allowing buret valve to discriminate smaller increments.

y. Continue from "n" above.

To Shut Down -

a. Turn "Titrate-Endpoint" switch to mid position.

b. Turn off main O_2 valve on top of tank.

c. Turn off "High Voltage".

d. Turn off automatic titrator.

e. Drain titration chamber; flush once with a chamber full of HCl solution or water, cover and leave stand.

f. If O_2 has stopped bubbling in H_2SO_4 solution, turn off small knurled valve on gage outlet.

g. Turn off "Filament Voltage".

Maintenance -

Periodically clean titration chamber and associated glassware with acetone or concentrated HCl.

Sulfate removal from minesoil and overburden samples before total sulfur determination in LECO furnace

Materials -

a. 28-mm ID polyethylene funnel.

b. 5.5-cm glass fiber filter paper.

c. Acid-inert filter funnel holder (polyethylene).

d. 2:3 HCl.

e. Mariotte bottle, at least 500-ml capacity, with height of outlet capillary adjustable to regulate outflow rate.

Procedure -

a. Taking care to not sharply crease the glass fibers, fold a filter to fit the polyethylene funnel.

b. With filter assembly on a suitable holder (small plastic vial), place onto pan of a balance and weigh 0.500 ± 0.001 gram of 60 mesh sample into the filter.

c. Place sample and filter onto funnel holder in sink or other suitable pan which can receive outflow from funnel.

d. Charge Mariotte bottle with 50 ml of 2:3 HCl; start siphon and adjust flow rate into funnel to avoid funnel overflow.

e. After sample has been leached with the acid, rinse out feed bottle and fill with 500 ml of distilled water; leach sample with water.

f. After leached sample has dried (overnight airdry or 50°C oven), carefully fold glass fiber filter paper around the sample and transfer to a ceramic crucible for total sulfur analysis in the LECO furnace.

g. Determine sulfur using standard LECO procedure, however add one extra scoop of Fe chips or powder.

POTENTIAL ACIDITY WITH PEROXIDE

Direct oxidation of reduced sulfur to acid with hydrogen peroxide and subsequent titration with a standard base has been suggested as the most attractive method of evaluating the acid potential of "acid sulfate soils" (Brinkman and Pons, 1972). Although they also advocate the use of peroxide oxidation to detect "net potential acidity" in acid sulfate soils containing carbonates, oxidative efficiency is greatly reduced at pH of 5.8 and above (Jackson, 1958). Earlier investigations (West Virginia University, 1971a) showed a close relationship between total sulfur content of fresh overburden samples and the amount of acid measured after the samples were treated with hydrogen peroxide. When the samples consisted of minesoils or weathered overburden materials, sulfate-sulfur, organic content, and calcium carbonate content unpredictably influenced the amount of acidity generated by peroxide treatment. The relationship between sulfur content and generated acidity for 49 minesoil and weathered overburden samples, where the samples had been treated with acid to remove sulfates and carbonates before both the sulfur determination and the peroxide treatment, has been statistically confirmed. Correlation between the acidity produced, and the pyritic plus organic sulphur content, was significant at the 0.001 level, with an r^2 value of 0.970. Acidity could be related to percent sulfur by the equation:

$$Y = 4.93 + 52.29\ X$$

where Y is total potential acidity, expressed as milliequivalents of hydrogen per one hundred grams, and X is percent pyritic plus organic sulphur.

Procedure

Note: If the sample contains no carbonates and no sulfates, and the pH is less than 5.5 in a 1:1 soil-water suspension, then Step 1 can be eliminated.

1. Place 3 grams of sample (< 60 mesh) into a funnel fitted with filter paper (11.0 cm., Whatman No. 41). Leach sample with 300 ml of 2:3 HCl (HCl:water) in funnel-full increments, followed by distilled water (in funnel-full increments) until effluent is free from chloride as detected by 10% silver nitrate. Airdry filter paper and sample overnight, or place in 50°C forced-air oven until dry.

2. Carefully scrape dried sample from paper surface and mix.

3. Weigh out accurately 2.00 grams of sample into a 300-ml tall form beaker. Add 24 ml of ACS Reagent Grade 30% H_2O_2 and heat beaker on hotplate until solution is approximately 40°C. Remove beaker from hotplate and allow reaction to go to completion, or for 30 minutes, whichever comes first. Three blanks for each batch of samples should be handled in the same manner. Caution: initial reaction may be quite turbulent when samples contain 0.1% sulfur or greater.

4. Add an additional 12 ml of reagent grade H_2O_2 (30%) to beaker and allow to react for 30 minutes, then place beaker on hotplate at approximately 90 to 95°C, solution temperature, for 30 minutes to destroy any unreacted H_2O_2 left in beaker. Do not allow to go to dryness.

5. Wash down the sides of the beaker with distilled water and make the volume of solution to approximately 100 ml.

6. Place beaker on the hotplate or over a Bunsen burner and heat the solution to boiling to drive off any dissolved CO_2, then cool the solution to room temperature.

7. Titrate the solution, with 0.0100 N NaOH that is free of CO_2 and protected from the atmosphere, to pH 7.0 using a glass electrode pH meter. Note: The NaOH must be standardized precisely with $KHC_8H_4O_4$ to obtain its exact Normality which will be used in the calculation.

8. Calculations:

   a. (ml of NaOH) x (Normality of NaOH) x (50) = meq (H^+)/100 g.

   b. meq H^+/100 g x 0.01 = tons H^+/thousand tons of material.

   c. One ton of H^+ requires 50 tons of $CaCO_3$ equivalent to neutralize it.

NEUTRALIZATION POTENTIAL

The natural base content of overburden materials is important in evaluating potential minesoils. Quantization of neutralizing bases, including carbonates, present in a rock was accomplished by treating the sample with a known excess of hydrochloric acid, heating to insure complete reaction, and determination of the unconsumed acid by titration with standardized base. This is a modification of the procedure used to measure the neutralizing equivalence of agricultural limestone (Jackson, 1958).

Procedure for Minesoil or Overburden Material

1. Weigh 2.00 grams of sample, ground to pass a 60 mesh (0.25 mm) sieve, into a 250-ml Erlenmeyer flask.

2. Carefully pipet 20.00 ml of 0.1 N HCl (the normality of which is known exactly) into the flask.

3. Heat nearly to boiling until reaction (acid plus carbonates) is complete; 5 minutes is usually sufficient.

4. Add H_2O to a total volume of 150 ml, boil 1 minute; cool.

5. Titrate using 0.1 N NaOH (concentration exactly known), to pH 7.0 using an electrometric pH meter.

   a. If the pH of the suspension is greater than 7.0 before beginning the back titration with NaOH, a $CaCO_3$ equivalent of over 50 tons per thousand tons of material can be assumed.

   b. If less than 3 ml of the 0.1 N NaOH is required to obtain a pH of 7.0, insufficient addition of acid to neutralize all of the base present is likely. Therefore, to obtain the most reliable results, the sample should be rerun using a greater amount of acid initially added to the sample.

   c. If an exact value of this high neutralizing capacity is desired, rerun the sample using a greater amount of acid initially, or using above procedure but substituting 1.0 N HCl and 1.0 N NaOH.

6. Calculate neutralization potential (NP) using equations a. through c.

   a. Millilitres of acid consumed by sample = millilitres of acid added to sample, minus millilitres of base required to neutralize sample times

$$\frac{\text{ml of acid (only) in a flask}}{\text{ml of base required to neutralize it}}$$

   b. Parts $CaCO_3$ equivalent/million parts of soil = (millilitres of acid consumed by sample) times N of acid times

$$\frac{100}{\text{grams of sample used}} \times \frac{10{,}000}{1} \times \frac{\text{50 grams of } CaCO_3}{\text{1 gram of } H^+}$$

   c. For a 2.0-gram sample:

      1. Tons of $CaCO_3$ equivalent/1000 tons = millilitres of acid consumed by sample times 25,000/1,000 times N of acid

      2. Tons of $CaCO_3$ equivalent/thousand tons of soil = millilitres times 25.0 times N of acid

   d. Maximum $CaCO_3$ requirement for neutralization of acid developed from total sulfur = %S times 31.24 (assuming all sulfur occurs as pyrite or marcasite).

The soil test analyses discussed in Smith et al. (1974) for pH, lime requirement, available phosphorus, potassium, calcium, and magnesium were carried out on overburden rock material pulverized to pass a 60-mesh sieve and, in the case of minesoils, crushed material passing a 2-mm sieve. The analytical procedures for available phosphorus and potassium are essentially those instituted by the North Carolina Agricultural Experiment Station (Nelson, Mehlich, and Winters, 1953) and used by several Eastern states. Available calcium and magnesium were determined in this same extract. The lime requirement test was that proposed by Woodruff (1948).

Analyses for available phosphorus by the sodium bicarbonate extraction, as discussed in Smith et al. (1974), were carried out using the method of Olsen et al. (1954) as described by Olsen and Dean (1965). The step-by-step procedure for this method follows.

PROCEDURE FOR DETERMINING AVAILABLE PHOSPHORUS IN MINESOILS.
(MODIFIED METHOD OF OLSEN et al., 1954)

Materials

1. 50-ml Erlenmeyer flasks with stoppers, or similar containers for phosphorus extraction step.

2. Funnels, 60-mm diameter, with funnel rack to hold several.

3. Whatman #40 or S & S 589-white, filter paper, 110-mm diameter.

4. 50-ml beakers to receive filtrate after extraction.

5. Decolorizing charcoal, Darco G-60 (J.T. Baker Chemical Co.) or equivalent.

6. Balance, capable of ±0.01-gram accuracy.

7. Shaking machine, Burrell Wrist-Action Shaker, or reciprocating shaker adjustable from about 50-200 excursions/minute.

8. 25-ml volumetric flasks.

9. Colorimeter or spectrophotometer, with filter or adjustment to provide 660-mu incident light.

10. Cuvettes or matched test tubes to fit above colorimeter.

11. Sodium bicarbonate ($NaHCO_3$) solution, 0.5 M, adjusted to pH 8.5 with 1 M NaOH. Mineral oil added to avoid exposure to the air; stored in a polyethylene container and made fresh every 2 months.

12. Ammonium molybdate, $(NH_4)_6 Mo_7O_{24} \cdot 4H_2O$, solution: dissolve 15 grams in 300 ml of warm distilled water. Filter if cloudy and allow to cool. Gradually add 342 ml of concentrated HCl and mix. Dilute to 1 liter.

13. Concentrated $SnCl_2 \cdot 2H_2O$ solution: 10 grams of large crystals dissolved in 25 ml concentrated HCl. Store refrigerated in a brown glass bottle. Prepare fresh every 2 months.

    a. Dilute $SnCl_2$: Add 0.5 ml of the concentrated $SnCl_2$ solution to 66 ml distilled water. Prepare the dilute solution for each set of determinations.

14. Standard P solution: Weigh 0.4393 g. KH_2PO_4 into a 1-liter volumetric flask. Add 500 ml distilled water and dissolve the salt. Dilute to 1 liter, and add 5 drops of toluene to reduce microbial growth.

15. Dilute P solution: Dilute 20 ml (pipet) of the P solution from step 14 to 1 liter with distilled water. This solution contains 2 µg of P per ml.

Procedure

1. Add 1.00 gram of < 60-mesh rock or soil sample, 1.7-cm decolorizing carbon, and 20 ml of $NaHCO_3$ solution to the 50-ml Erlenmeyer flask. Stopper the flask.

2. Shake for 30 minutes, at 20°C, using a shaking speed of 2 on a Burrell wrist-action shaker, or 120 excursions per minute on a reciprocating shaker.

3. Filter through filter paper specified; shake flask before pouring suspension into filter funnel.

4. Pipet 10 ml of filtrate into a 25-ml volumetric flask. (If necessary to interrupt work, stop here.)

5. a. Slowly add, with a pipet or calibrated dispenser, 5 ml of ammonium molybdate solution. Shake gently to mix well (pH of the solution after adding molybdate should be between 3.0 and 4.0. With some alkaline soils addition of more acid may be necessary to assure the indicated pH for consistent color development. With minesoils studied, however, 5 ml of molybdate has been sufficient and has avoided excess acidity with extremely acid samples).

    b. Wash down neck of flask with a small amount of water and dilute to about 22 ml.

6. Pipet 1 ml of the dilute $SnCL_2$ solution into the flask, dilute to volume, and mix immediately holding the top of the volumetric flask tightly closed (gases are generated during this mixing); be sure solution is thoroughly mixed before releasing hand pressure on the cap of the flask.

7. Ten minutes but less than 20 minutes after adding the dilute $SnCL_2$ to the flask and mixing, measure the transmittance (%T) of the blue solution, using the colorimeter or spectrophotometer at 660 mu. Be sure to understand instructions for operating the instrument correctly.

8. Obtain P concentration from standard curve prepared as follows:

   a. Pipet aliquots, containing from 2 to 25 µg of P (this gives a range of from 0.08 to 1.0 µg/ml in the 25 ml flask), of the dilute P solution into 25 ml volumetric flasks and add 5 ml of the $NaHCO_3$ extracting solution to each flask.

   b. Develop the color as in step 4.

   c. Plot the %T vs P concentration in the 25 ml flask on single-cycle, semilog graph paper, or Absorbance (A) vs P concentration on linear graph paper.

Calculations

If a 1.0-gram sample is extracted with 20.0 ml of extractant, and a 10.0-ml aliquot of the filtered extractant is taken into a 25-ml volumetric flask for color development then:

ppm available P in the soil =
    ppm P in sample, taken from standard curve x 50.

IMMEDIATE LIME REQUIREMENT DETERMINATIONS

Determinations of the lime requirement of minesoils by $Ca(OH)_2$ titration are discussed in West Virginia University (1971b), and further interpretations appear in Smith et al. (1974). A further study, involving 32 minesoil samples selected from an Upper Freeport coal mining area, was undertaken to investigate the suitability of the 5-minute-boiling modification of the $Ca(OH)_2$ incubation reported by Abruna and Vicente (1955). Their method, slightly modified for minesoils, follows.

Procedure

Place 10-gram samples of sieved (10 mesh) air-dry soil in beakers. Dilute with 50 cm of distilled water and add varying increments of 0.03 N $Ca(OH)_2$ solution, depending on the expected exchange capacity and base saturation of the soil. Boil on a hot plate for 5 minutes (intermittent stirring of the samples may be necessary to avoid excessive foaming). Cool in a water tray to 25°C and determine the pH of the suspension using a glass electrode. Buffer curves relating pH values to quantity of lime prepared from these data are then used to determine the lime required to raise the soil pH to any desired level.

Figure B-1 compares the two methods for determining lime requirement by titration. The results compare favorably and considerable time is saved by the 5-minute-boiling method. By boiling the solution for 5 minutes, the time for reaching equilibrium was reduced from 100 hours to 1 hour.

Certain theoretical considerations in addition to a limited study of data accumulated to date suggest that some relationship exists between the lime requirement of soils as determined by the various buffer methods, and the

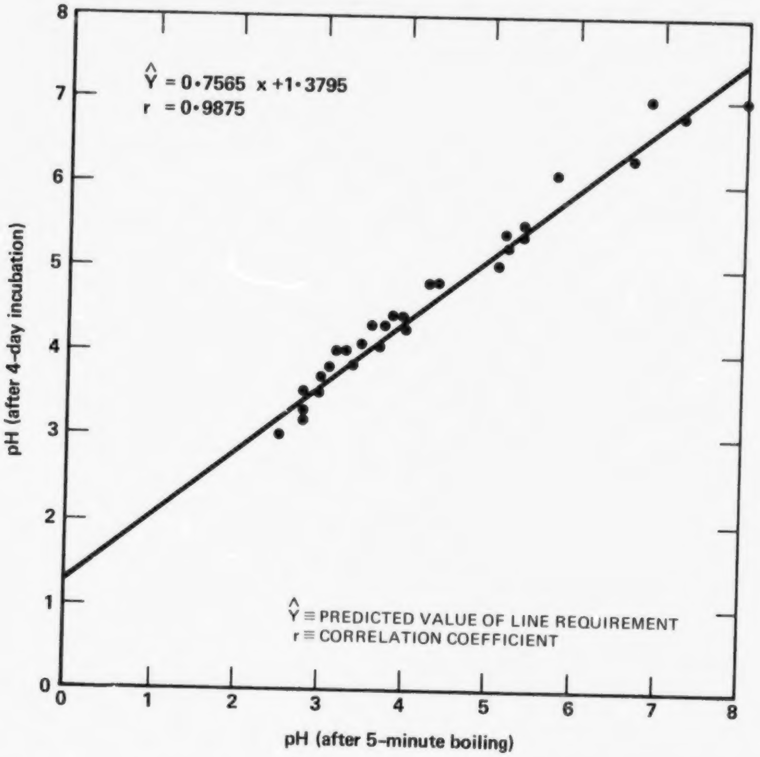

Figure B-1. Comparison of lime requirements of 32 upper minesoil samples by direct $Ca(OH)_2$ titration using a rapid 5-minute-boiling method and the standard 4-day incubation (Smith et al., 1974).

titratable acidity as detected in the neutralization potential (NP) measurement discussed earlier.

Figure B-2 indicates that Soiltest Lime Requirement (modified Woodruff buffer method) and neutralization potential are closely correlated. In these predominantly sandstone minesoil samples positive and negative values of the neutralization potential were used. The high correlation shows that it is possible to predict lime requirement from neutralization potential.

SOIL ACIDITY

Several constituents contribute to the development of minesoil acidity. These sources (humus, alumino-silicates, hydrous oxides, pyritic materials and soluble salts) may contribute independently or by interaction. The more common methods of measuring acidity are pH, electrometrically by means of glass electrode, exchangeable acidity using unbuffered KCl, and titratable acidity, using unbuffered solution.

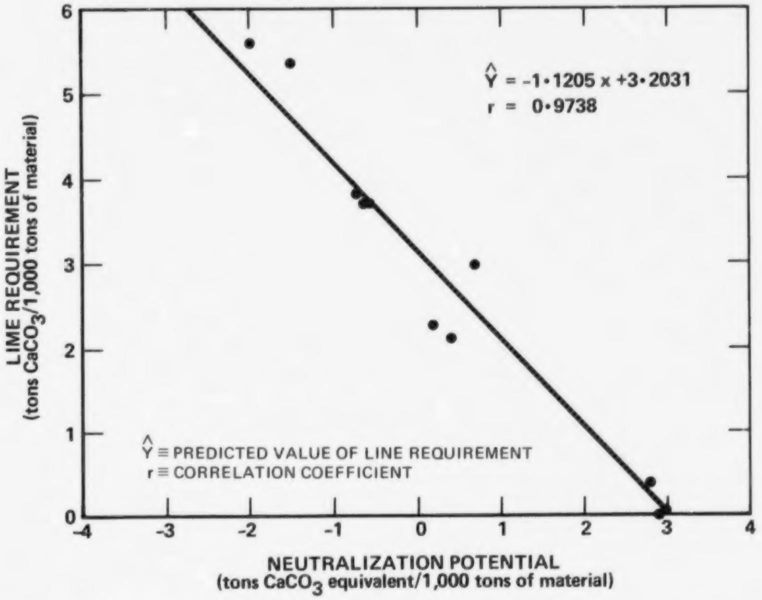

Figure B-2. Relationship between soiltest lime requirement and neutralization potential (Smith et al., 1974).

Two important factors affecting soil pH measurements are (1) the soil/water ratio and (2) the presence of soluble salts. The "suspension effect" results in a different pH reading when the electrode is placed in the sediment as opposed to the supernatent liquid. The pH of the sediment is usually lower for acid soils. Ideally, pH measurements should be taken in a "thin paste". At West Virginia University's soil testing laboratory a 1:1 soil/water ratio is used, which gives an ideal thin paste or slurry with some soils. With sandy soils and many coarse or medium textured minesoils the 1:1 mixture must be agitated while the pH is being determined in order to assure suspension. A satisfactory alternative is to use less water relative to minesoil.

Soluble salts may have a pronounced effect on soil pH. As the salt concentration increases, the measured pH commonly decreases because the cation of the salt replaces the exchange acidity on the soil colloid releasing the acidity to the soil solution and decreasing the pH.

Two procedures have been used to overcome the salt effect. One method is leaching out the soluble salts with water and then measuring the pH. The second method is to add a salt solution instead of distilled water to the soil before measuring pH. One tenth normal KCl and 0.01 M $CaCL_2$ are the salts normally used. The salts in the soil solution are assumed negligible compared to the salt solution added to the soil. The more common approach in the United States is to determine pH in a distilled water slurry, realizing that significant soluble salts may be present, depending on character of the sample.

The pH measurements of the 1:1, soil/water slurry (agitated to assure soil suspension) were all higher than those of the 1:1, soil/salt solution (Table B-1). The relationship between the two methods was good, resulting in a correlation coefficient of 0.858; however, when the pH measurements in water and salt solution were correlated with the extractable aluminum, the correlation coefficients were 0.0319 and 0.0954 respectively. There are two reasons for these poor relationships: (1) all the pH measurements were below 3.7, where acidity is dominantly from mineral acids in the soil solution and the range of pH from 4.0 to 5.5 is where soil acidity is dominated by exchangeable aluminum, and (2) the range of pH values (2.9 to 3.6 for water slurry and 2.4 to

Table B-1. COMPARISON OF TOTAL ACIDITY AND pH BY TWO DIFFERENT METHODS ALONG WITH EXTRACTABLE ALUMINUM ON 3- TO 8-YEAR OLD UPPER FREEPORT MINESOILS (Jackson, 1958).

Sample	Ba Cl_2-TEA pH 8.2 meq H+/100 g	1NKCl meq $\bar{H}$+/100 g	1NKCl meq Al+++/100 g	pH	
				H_2O 1:1	1NKCl 1:1
QQ 1-1	12.26	3.87	2.75	2.9	2.4
QQ 1-2	11.28	3.87	3.00	2.1	2.5
QQ 1-3	10.79	3.51	2.56	3.1	2.6
QQ 2-1	8.34	2.50	1.89	3.2	2.6
QQ 2-2	9.48	2.85	1.72	2.9	2.5
QQ 2-3	8.01	2.55	1.99	3.3	2.7
QQ 3-1	13.73	4.89	4.22	3.3	2.6
QQ 3-2	10.46	3.26	2.39	3.2	2.5
QQ 3-3	13.24	5.09	4.81	3.4	2.7
RR 1-1	11.61	3.36	2.70	3.2	2.7
RR 1-2	11.77	3.62	2.92	3.0	2.7
RR 1-3	12.59	4.02	3.17	3.1	2.7
RR 2-1	10.79	3.62	3.11	3.2	2.7
RR 2-2	9.81	3.26	3.00	3.2	2.8
RR 2-3	10.95	3.67	3.00	3.2	2.7
RR 3-1	10.63	3.46	2.50	3.1	2.7
RR 3-2	11.45	3.87	2.92	3.0	2.6
RR 3-3	9.16	3.05	2.22	3.1	2.7
SS 1-1	5.72	1.99	1.61	3.6	3.0
SS 1-2	7.52	2.70	2.22	3.5	2.9
SS 1-3	7.68	2.65	2.22	3.5	2.9
SS 2-1	10.95	3.87	3.36	3.3	2.8
SS 2-2	7.57	2.85	2.22	3.5	2.9
SS 2-3	11.77	3.77	3.31	3.4	2.8
SS 3-1	7.19	2.65	2.22	3.5	2.9
SS 3-2	6.38	2.34	1.83	3.5	2.9
SS 3-3	6.70	2.04	1.67	3.6	3.1

3.1 for the salt solution slurry) is so small that other uncontrolled variables dominate. The exchange acidity of a soil is thought of as acidity that can be replaced by a neutral, unbuffered salt such as KCl. The titratable acidity is that amount of acidity which is neutralized at a selected pH such as 8.2 for the $BaCl_2$-triethanolamine (TEA) method. The latter has the rationale of measuring the many different components of soil acidity, and corresponds to the definition of a calcium-saturated soil.

The soil acidity measurements (Table B-1) indicate that the $BaCl_2$-TEA method results are higher than those from the 1N KCl method by a factor of approximately 3:0; however, both methods are closely related as evidenced by a correlation coefficient of 0.945. When data of both methods were compared with exchangeable aluminum, the 1N KCl method correlated more closely (r=0.948) than the $BaCl_2$-TEA method (r=0.840), indicating that the latter measures acidity other than just that contributed by the exchangeable aluminum.